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PHYLLOSTICTA LEAF SPOT, FRUIT BLOTCH, AND CANKER OF THE APPLE: ITS ETIOLOGY AND CONTROL

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PHYLLOSTICTA LEAF SPOT, FRUIT BLOTCH, AND CANKER OF THE APPLE: ITS ETIOLOGY AND CONTROL[a]

By EMIL FREDERICK GUBA[b]

The increasing prevalence and seriousness of apple blotch in Illinois and thruout the United States, and the inadequacy of present control measures emphasize the need of detailed study of the life history and habits of the causal organism, *Phyllosticta solitaria* E. & E. Since the first published account of the disease on the commercial apple in 1902, valuable observations and isolated facts have been presented by many investigators. Existing publications on the disease, however, show a lack of knowledge of many important phases of the organism necessary for its successful control.

THE DISEASE

Names Applied

Before anything definite was known about apple blotch, fruit growers regarded it as an unusual stage of apple scab or apple bitter rot. Up to 1907, the disease was known variously as "apple blotch," "fruit blotch," "dry rot," "black scab," "late scab," "cancer," "tar blotch," "Phyllosticta," "Phyllostictose," "star fungus," "Phyllosticta spot," or "Phyllosticta on the apple." As more was known about the disease it came generally to be referred to as apple blotch, and this is the name that will be used in this bulletin.

Historical

Specimens of the disease were first collected in October, 1893, by L. M. Underwood[92] on the leaves of the American crab apple (*Pyrus coronaria* L.) in Montgomery county, Indiana. They were submitted for examination to J. B. Ellis, who determined the causal organism to be a Phyllosticta, to which he gave the name *Phyllosticta solitaria;* in 1895, he furnished a meagre description of it. A few months previous to the publication of the description of *Phyllosticta solitaria,* by Ellis and Everhart,[30] M. B. Waite, pathologist of the Bureau of Plant Industry, U. S. Department of Agriculture, photographed blotched

[a] The results presented in this bulletin form part of a thesis submitted by the author to the Graduate School of the University of Illinois in partial fulfilment of the requirements for the degree of doctor of philosophy in botany, May, 1923. The writer wishes to express to Dr. H. W. Anderson, Assistant Chief in Pomological Pathology in Horticulture, and to Dr. F. L. Stevens, Professor of Plant Pathology in Botany, his appreciation for their supervision of the study and for their suggestions and criticisms in the preparation of the manuscript. He is indebted to Dr. C. F. Hottes, Professor of Plant Physiology in Botany, for the use of his laboratory and for suggestions in the study of the temperature relations of the fungus in culture, and to others who have shown interest in the work.

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fruits of *Malus Malus* L. collected from localities about Washington, D. C., and identified the causal organism as a species of Phyllosticta (Fig. 1). Owing to the uncertainty which existed at that time concerning the causal agent of the frog-eye apple leaf spot, Waite supposed that the fruit blotch and the frog-eye leaf spot were the results of the same organism, but was in no way certain of his hypothesis. So

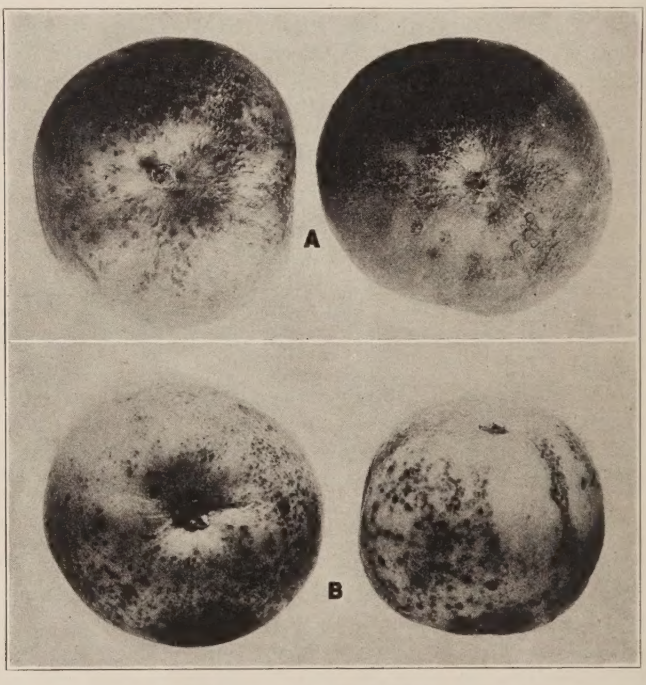

FIG. 1.—APPLE BLOTCH

Specimens collected at Garrett Park, Montgomery county, Maryland, by M. B. Waite; (A) 1897, (B) 1895 (photographs by M. B. Waite).

many Phyllostictas on the apple were then known that he was unwilling to make any statement as to the causal fungus further than that it was a species of Phyllosticta.[a] In 1902 Clinton[17] gave the first published account of the disease on the commercial apple and called attention to its prevalence in the apple regions of southern Illinois. Clinton cultured the organism and described its microscopic characters. He considered the fungus a new species of the genus Phyllos-

[a]Information obtained from personal correspondence. These collections by M. B. Waite represent the earliest record of apple blotch on the commercial apple.

ticta. At about the same time Faurot[31] of Missouri had his attention called to the disease by growers who had mistaken it for a dormant condition of bitter rot.

What appear to be the first experiments involving the control of apple blotch were conducted in 1903 by C. S. Crandall[23] of the Illinois Agricultural Experiment Station in the investigation of the comparative efficiency of Bordeaux dust and liquid Bordeaux in the control of apple insects and diseases. The first investigation directed primarily toward the control of apple blotch was conducted by Scott and Quaintance[77] in 1906 in Benton county, Arkansas. Their spraying experiments resulted in the use of a spray schedule, which at that time gave satisfactory control of the disease.

To Sheldon[86] we are indebted for knowledge of the fact that *Phyllosticta solitaria* E. & E. on the leaves of *Pyrus coronaria* is identical with the organism producing the bark canker, leaf spot, and the fruit blotch of the commercial apple. Sheldon did not attempt cross inoculations, and type specimens of the fungus were not examined. His conclusions, however, were generally accepted.

At the same time Scott and Rorer,[78] at Bentonville, Arkansas, established by isolation of the fungus, comparison of its growth in culture, and by inoculation of the host with spores from natural sources, the identity of the organism causing the bark canker, leaf spot, and fruit blotch of the apple.

Stevens [87, 88] in 1907 found blotch for the first time in North Carolina. In 1908 Garman[37] reported it in Kentucky, Morris and Nicholson[52] cited its prevalence and seriousness in Oklahoma, and Orton and Ames[56, 57] reported its general distribution in the region extending from Maryland and the Carolinas to Arkansas and Missouri. Douglass[26] in 1909 and McCormack[53] in 1910 reported its prevalence in southern Indiana, and in 1910 Selby[82] and Gloyer[39] recorded it for Ohio; Orton* found it in Pennsylvania, and Beach* in South Dakota. As early as 1912, according to Cook,[22] apple blotch was common in New Jersey.

Scott and Rorer[79] in the period 1906 to 1909 conducted the first general study of the apple blotch fungus. Their study dealt briefly with the etiology of the disease, the cultural and morphological characters of the fungus, its life history, and control.

Since 1912 some attention has been directed to the control of apple blotch with dormant sprays. Such a possibility was originally conceived by growers in Illinois, was first given experimental attention by Watkins[106, 107] of Illinois, and later was taken up on several occasions by the Agricultural Experiment Stations in Illinois and Indiana.

*Information obtained by personal correspondence.

Lewis[51] in 1913 presented an extensive account of apple blotch embodying descriptions of the disease on various varieties of apples and the results of his experiments in its control.

Since the publication of the paper by Scott and Rorer,[79] experimental work on blotch control has been concerned particularly with the relative merits of Bordeaux and lime sulfur, and the time of the applications. In connection with this experimental work the results of Lewis,[51] Blair et al.,[8] Gunderson,[42-45] Cooper,[20] Roberts,[67-69] Beach,[5-7] Brock,[9, 11, 13-15] and Selby[82, 83] should be noted. The results of Beach[5-7] demonstrated the value of a spray two weeks after petal fall, supplementary to applications recommended by previous investigators. The probability of primary infection earlier than three weeks after petal fall had been suggested previously by Lewis[51] of Kansas, Cooper[20] of Nebraska, Rolfs[71, 72] of Oklahoma, Brock[13] of Illinois, and Stover et al.[90] of Ohio.

In 1917 Roberts[67] confirmed the previous inoculation work of Scott and Rorer by successfully inoculating the host with spores from pure culture. In 1921 Roberts[68] demonstrated by artificial inoculation that only the current season's growth is susceptible to blotch infection.

In 1920 Anderson[3] reported the distribution of the disease in Illinois and outlined a plan embodying exclusion, prevention, quarantine, and inspection measures, whereby he believed it possible to restrict the disease to its confines in Illinois at that time, and thus prevent its northward migration.

In 1922 Gardner[35] of Indiana found that most of the apple blotch cankers are the direct result of petiole and bud scale infections. He reported that the mycelium from the basal petiole lesions crosses the abscis layer before leaf fall, invades the bark and produces a canker about the bud which, in the majority of cases, becomes conspicuous the following spring. Lewis,[51] and Scott and Rorer[78] observed that cankers originated in this manner, but the seriousness of this method of infection was emphasized by Gardner.

In 1923 Gardner and Jackson[36] suggested surgical measures to eradicate cankers from young apple stock and thus avoid an increase of new cankers in young orchards.

The timely reports of the Plant Disease Survey, U. S. Department of Agriculture,[93-102] from 1917 to the present, have been exceedingly valuable as a source of information on the annual prevalence, distribution, and losses from this disease.

PROBABLE ORIGIN

Collections of apple blotch from widely scattered localities (see page 481) prior to 1902 establish the proof of the wide distribution of

the fungus even at that early period and support the contention that the disease did not arise locally on the commercial apple.

The original host of this fungus was probably the native crab apple (*Pyrus coronaria*) and during the past few years in Illinois and Indiana the fungus often has been found on this host. Sheldon[86] found it on this species of native crab apple in West Virginia, and Scott and Rorer[79] in Pennsylvania. The fungus still exists in a severe form on this host, but in a less serious degree than on susceptible varieties of commercial apples. This may be explained thru the fact that

FIG. 2.—DISTRIBUTION OF APPLE BLOTCH IN THE UNITED STATES, 1916-1923

the native crab may have gradually developed partial immunity during its long period of susceptibility in its native habitat. With the rise and development of commercial fruit growing in the eastern half of the United States, the extensive planting of varieties susceptible to the apple blotch fungus, and favorable climatic conditions, the fungus adapted itself to growth on the commercial apple and developed into a serious disease producer.

The disease first became seriously destructive in the Ozark apple region. During the period 1900 to 1902 in southern Illinois, Arkansas, and southern Missouri it was generally prevalent and serious. In the time which has since elapsed it has spread over most of the eastern half of the United States (Fig. 2).

DISTRIBUTION AND PREVALENCE IN ILLINOIS

Clinton[17] stated that apple blotch was found in a number of places in southern Illinois by Burrill in 1901; that growers were aware of

its presence earlier, and that it was present in an orchard at Dubois, Washington county, for some time previous to 1901. Since its first reported appearance, it has developed into epidemic form in the centers of apple production.

No information is available to show the periodic progress of the disease northward. Crandall,[23] in 1903, found apple blotch prevalent on Ben Davis trees south of Olney, in Richland county, and in 1912 Ruth[8] reported infection of approximately 70 percent of the apples on unsprayed Ben Davis and Jonathan trees in an orchard at Flora.

The accounts of the spraying experiments of Crandall[23] in 1904, and of Foglesong[32] in 1909 at Griggsville, Pike county, do not include data on apple blotch. Likewise, the absence of any statements concerning apple blotch in the accounts of the spraying experiments of Gunderson[8] in Ben Davis orchards in Pike county in 1911 and 1912, indicates that apple blotch was not present or at least was not serious in southwestern Illinois in this period.

The account of the spraying experiments of Watkins[8] with fifteen-year-old Ben Davis trees at Neoga, Cumberland county, for three seasons, 1910 to 1912, does not mention apple blotch. Blotch, evidently, was not present in the orchard and very likely not established in the vicinity.

With the meager information available, together with a knowledge of the development of fruit growing in Illinois, it seems probable that the fungus came into Illinois from the apple-growing region to the southwest, and that the disease appeared at about the same time in all of southern Illinois coincident with the extensive development of the apple industry. The Pike-Calhoun apple section, being of recent development and with different conditions, remained relatively free of blotch until 1913.

Knowledge of the disease in central Illinois is limited to recent years. Evidence points to the appearance of the disease on Northwestern Greening in the University orchards, Champaign county, in 1917. It appeared at about the same time on Northwestern Greening at Lilly, Tazewell county, at Yates City, Knox county, and near Danville, Vermilion county. At Lilly the disease may also be traced to infections of 1917 on Ben Davis, Missouri Pippin, and Duchess varieties. In 1921, in the Lilly orchards, 90 percent of the fruit of Northwestern Greening trees was affected with blotch, which indicates that epidemic development of the disease after its first appearance at Lilly was but a matter of a few years.

In 1920 the disease was found on Red Astrachan in Peoria county, on Northwestern Greening and Duchess in Ogle county, and on Duchess in Kendall county. In Ogle and Kendall counties the epidemic development of blotch on Duchess trees in a home orchard lends

support to the belief that the disease may have been present since 1917-1918. In 1921 the prevalence of apple blotch was observed on Northwestern Greening at Rome, Peoria county. In the same year a trace of it was found on the same variety near Galena, Jo Daviess county. The appearance of this disease in isolated regions in central and northern Illinois within the last few years suggests that its distribution in this region is comparatively recent.

Apple blotch to-day is present thruout Illinois. South of the 40th parallel, i.e., south of the tier of counties extending east and west approximately from Adams to Vermilion counties, it is very prevalent and is a limiting factor in the commercial production of susceptible varieties of apples. In the Pike-Calhoun apple section, however, the disease is generally much less severe and less prevalent than in the more central and southern sections of this area. In the area of the 41st parallel, i.e., extending east of Henderson, Hancock, and the northern half of Adams counties, apple blotch is now rather generally present and well established on Duchess and Northwestern Greening and is rapidly passing to other less susceptible varieties. Its progress in this section has been comparatively slow in the absence of extensive plantings.

In northern Illinois apple blotch is local and found only in scattered places. Severe cases of it have been found in home orchards, where spraying and the culture of the apple often are neglected.

PLANTS AFFECTED

Apple blotch is strictly a disease of certain species of the genus Malus of Hall. The disease has never been found on any other host, altho recently Seaver[81] has named *Crataegus sp.* as a host for the fungus.

The confusion existing in the nomenclature of our native midwestern crab apples renders an accurate designation of the susceptible species difficult. In Illinois, *Malus lancifolia* Rehd. and *Malus coronaria* L. are very susceptible and *Malus angustifolia* Michx. is moderately so. The disease has been found occasionally on *Malus angustifolia* in Union county, and on *Malus lancifolia* and *Malus coronaria* in central Illinois and central Indiana. The common prairie crab apple (*Malus ioensis* Britt.) and its varieties are resistant; the disease never has been found on them.

ETIOLOGY

MORPHOLOGY OF THE PATHOGENE

Pycnidia

The pycnidia vary in size and form according to the organs of the plant affected. They are smallest on the leaf spots, being globose or sub-globose and with a thin wall. On the petioles they are similar in form, but somewhat larger. On the fruit they are considerably depressed and elliptical, with thick lateral walls. On the bark they are very large and the carbonaceous walls are more extensively developed than elsewhere.

On the leaf spots the pycnidia have a small rostrate ostiole which measures 9 to 12μ long and 7 to 12μ wide (Plate 1, Fig. H, I). The pycnidia vary in diameter from 60 to 95μ. The pycnidial wall is comparatively thin, generally consisting of one or two layers of dark-colored cells and measures 6 to 7μ wide. The wall is much thicker at the top and after the formation of the ostiole the thickened wall is retained around the short neck. Next to the wall within are the narrow sporogenous layers of hyaline parenchyma cells bearing conidiophores.

The pycnidia on the petioles are commonly larger than those formed on the leaf spots and measure 62 to 119μ in diameter, and have a definite, thin, dark-colored, and regular wall (Plate 1, Figs. D, G, J). About the ostiole the walls are broader and the cells are denser than at the sides and base of the pycnidium. The beak measures 12 to 14μ long and 9 to 12μ wide. Within the narrow dark-colored wall the larger hyaline sporogenous cells with conidiophores appear in sharp contrast.

On the fruit the pycnidia are black, punctiform, and prominent (Plate 1, Figs. E, F). They may be aggregated and fused, but usually their individuality is retained. They are decidedly depressed or elliptical and almost twice as wide as deep. The lateral walls are 14 to 16μ thick and the basal wall is about 4.75μ thick. The ostiole is indefinite, without a neck, and usually the wall around it is as broad as the lateral walls. The diameter of the stoma varies from 12 to 23μ. The wall is regular and definite, and adjoining it within are the hyaline cells of the thin sporogenous layer. The pycnidia on the fruit vary in size, from 57 to 95μ deep and 107 to 166μ wide. Upon the discharge of spores in summer the sporogenous tissue lining the interior of the pycnidium is rejuvenated and eventually fills the entire cavity while the ostiole is closed by the growth of the wall cells. During the fall and winter months the interior is occupied by pseudo-paren-

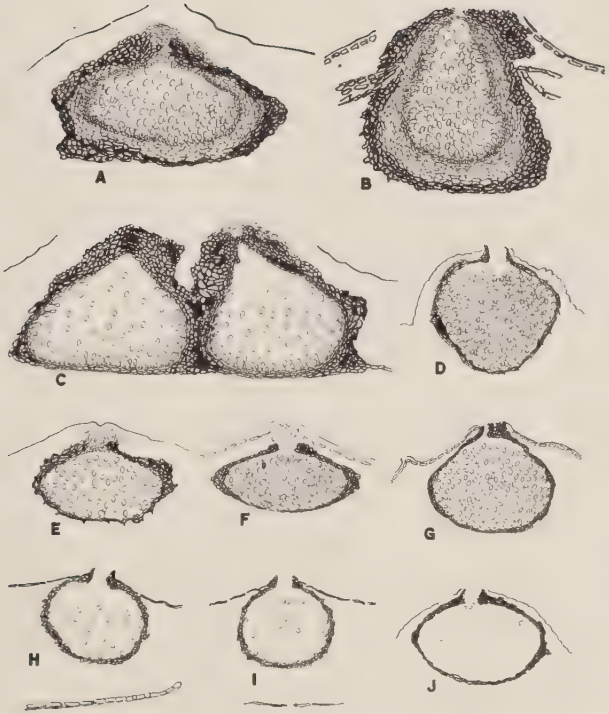

PLATE I.—SECTIONS THRU PYCNIDIA OF *P. solitaria*, SHOWING THE VARIATION IN SIZE AND FORM

(A, B) From bark cankers, the original pycnosclerotia; (C) from the advancing area of the canker formed in the spring; (D, G, J) from petioles; (E, F) from the fruit in June and July; (H, I) from the leaf blades.

chyma tissue enclosed in a thick carbonaceous wall. Extensive enlargement of the pycnidium occurs and often results in the fusion of the pycnidia. Such fruits with dense, thick, carbonaceous walls, enclosing a hyaline parenchyma context have been named pycnosclerotia (Fig. 3) by Reddick.[66, a]

On the bark two types of fruiting bodies are recognized: first, the pycnidia which form and function in the same season; and second, the pycnosclerotia which form in the late summer, pass the winter in a dormant condition, and function the following spring (Plate 1, Figs. A, B, C, and Fig. 3). Both forms at first resemble the pycnidia on the fruit in form and shape; depressed, wider than long, and with thick lateral and thin basal walls. The pycnidia usually develop a distinct ostiole and the thickness of the wall is more or less limited. In pycnosclerotia, the ostiole is usually indefinite and results from the rupture and removal of a part of the thick protective apical wall.

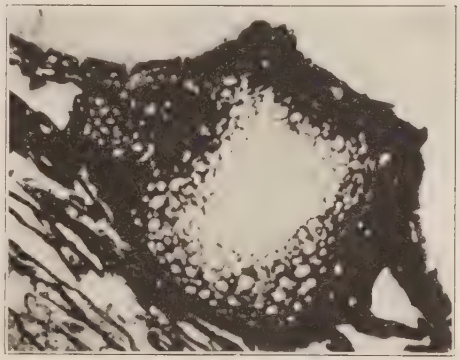

FIG. 3.—SECTION THRU A PYCNOSCLEROTIUM OF *P. solitaria* FROM A CANKER COLLECTED IN DECEMBER

Note the dense, carbonaceous wall and the hyaline interior parenchyma context.

Pycnosclerotia formed in late summer are in the following spring comparatively large, with thick, carbonaceous walls and without a definite ostiole. Spore formation commences in the center of the pseudo-parenchyma early in the year and the sporogenous layer which is formed gradually progresses outward. When sporulation is complete only the dark wall cells remain, enclosing the spores. Apically and laterally the walls are broader than at the base. The apical wall measures from 23 to 48μ thick; the lateral wall from 35 to 47μ, and the basal wall from 7 to 28μ. The pycnosclerotia are globose or sub-

[a] Reddick first used the term pycnosclerotium referring to a pycnidium with a thick carbonaceous wall enclosing a pseudo-parenchyma context of large hyaline cells which gives rise to a perithecium. Since perithecia have never been found to result from the differentiation of the pycnosclerotium of *P. solitaria*, the word is here used in a slightly different sense from that of Reddick, altho the form and structure of the fruit is in all respects the same.

globose. The ostiole measures from 23 to 59μ wide. The pycnosclerotia measure 155 to 274μ wide and 107 to 238μ deep.

Pycnospores

The pycnospores are ovoid or broad-elliptic, unicellular, hyaline, multi-guttulate, with a smooth wall which occasionally is partly covered at the broad end by an elongated, gelatinous appendage (Figs. 4, 9A[1]). The guttules are ordinarily uniform in size and form and evenly distributed in the cell tho often they are fused to form broad, greenish, irregular bands. In immature spores commonly one large guttule may almost fill the entire spore cell. The spores range in size from 7 to 11μ long and 6 to 8.5μ wide.

FIG. 4.—SPORES OF *P. solitaria* FROM PURE CULTURE

The spores of *Phyllosticta solitaria* from the pycnosclerotia bear a gelatinous, hyaline appendage which is at first very long and narrow, and considerably broadened at the base. It envelops about one-half of the spore at the broad end. The appendage may appear as a thick cap over the broad pole of the spore. This gelatinous cap or appendage has never been observed on spores from pycnidia which form and function in the same season; however, it is constant on the spores in the pycnosclerotia in the host and in artificial culture.

Other Phyllostictas show morphological characters similar to those of *Phyllosticta solitaria*, e. g., the imperfect forms of *Guignardia bidwellii* (E) V. & R. and *Guignardia vaccinii* Shear. Shear[84] in the study of the above forms noted the gelatinous appendage on the spores of *Guignardia bidwellii*. He described and figured similar appendages on the imperfect spores of *Guignardia vaccinii*.

Stewart[89] has described and illustrated similar appendages on the imperfect spore form of *Guignardia aesculi* (Pk.) Stewart. These descriptions agree with the character of the appendages on the spores

of *P. solitaria* from pure culture and from the pycnosclerotia in the host cankers.

Conidiophores

The conidiophores arise from a hyaline sporogenous layer of cells which is supported by a colorless pseudo-parenchymatous sheath lining the dark wall of the pycnidium (Plate 2). Sometimes the pycnidial membrane is not sharply limited, but appears gradually to differentiate, on the interior, into hyaline pseudo-parenchyma tissue.

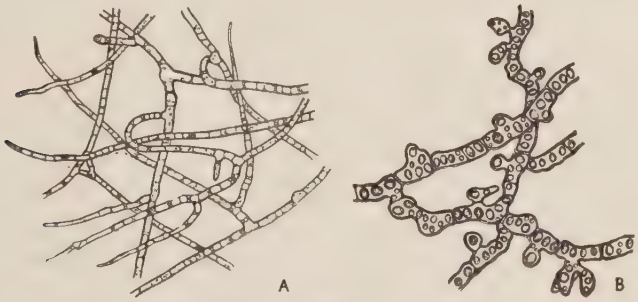

FIG. 5.—MYCELIUM OF *P. solitaria* FROM PURE CULTURE
(A) From margin of a young colony, (B) from an old culture.

This tissue does not react readily with common stains and appears more or less hyaline and somewhat obscure in stained sections.

The sporogenous layer is composed of very small and narrow cells from which the conidiophores arise. The conidiophores are simple, unicellular, excepting in the pycnosclerotia, where in the early stages of differentiation they are long and septate. They may be filiform, long, obclavate, and irregularly curved or straight; or they may be short, broad, straight, columnar, and almost as wide as the supported spore. They usually measure from 4 to 11μ long and 1 to 3μ wide. Commonly they taper, being broader at the base than at the apex.

Mycelium

The mycelium in culture is composed of septate, pale green hyphae which branch irregularly. The mode of branching, the irregular form, size, and the bulging of the cell walls are very characteristic.

The young, long, slender, and actively-growing hyphae measure about 2 to 3μ in diameter; septa are rare and the walls are not constricted (Fig. 5, A). Occasional bulging lateral walls mark the beginning of new filaments. Anastomosis is frequent along the walls. Transversely in the cells there are definite, rather large, irregularly-shaped, colorless vacuoles and bands of a pale olivine substance. The

color of the young colonies in culture is due probably to a colored pigment in the globules and bands of the substance along the walls and across the cells.

In the old mycelium the cells are short and thick, 6 to 8μ wide and occupied by large globules of a greenish color; septation is frequent and the walls are prominently constricted at the septa and at the bases of the short, stout branches that arise at irregular angles (Fig. 5, B). The anastomosis of these stout cells produces a very irregular network.

NOMENCLATURE

The original description of *Phyllosticta solitaria* was published by Ellis and Everhart[30] in 1895, as follows:

"*Phyllosticta solitaris* E. & E. On leaves of *Pyrus coronaria*, Crawfordsville, Ia., Oct., 1893. Prof. L. M. Underwood. Spots minute, 1 millimeter, round pale-white, with a darker border. Perithecia epiphyllous, solitary, one in the center of each spot, 75μ diameter. Sporules sub-globose, hyaline, nudeate, 5 to 6μ diameter."

The locality of this collection has been misrepresented by many. Saccarado[74] refers to the collection from "Iowa, Amer., bor.," but this misrepresentation is due to Ellis' incorrect abbreviation of Indiana, namely "Ia." on the original packet. Saccardo changed the ending of the specific name "solitaris" to "solitaria," since the gender of Phyllosticta, by common usage, is feminine.

Type specimens of the fungus were not available for personal study. Thru the kindness of Professor H. M. Fitzpatrick, the specimen in the Everhart herbarium (Vol. 2, p. 57) at Harvard University was examined and compared with specimens of the fungus on apple foliage from Illinois. He writes, "I feel no hesitancy in saying that your material agrees with the type in external appearance." Scott and Rorer[79] examined the type specimen of *Phyllosticta solitaria* from the New York Botanical Gardens and found that the spores were identical with those of the apple blotch fungus.

The genera Phoma and Phyllosticta are very large, the former comprizing approximately 1,700 form-species and the latter more than 1,100 form-species. Allescher[2] calls attention to certain differences between these genera, such as the small, sometimes indistinct papilla, and filiform, sometimes short or indistinct conidiophores in Phoma, and the relative absence of the small papilla, and the very short, rarely distinctly developed or absent conidiophores in Phyllosticta. They are further segregated in that Phyllosticta is only leaf-inhabiting while Phoma occurs on branches, twigs, stems, pedicels, petioles, and on the needles of the conifers. In practice it is customary to regard a species as a Phyllosticta if on the leaves, and as a Phoma if on the stems. This artificial classification is unsatisfactory and worthless.

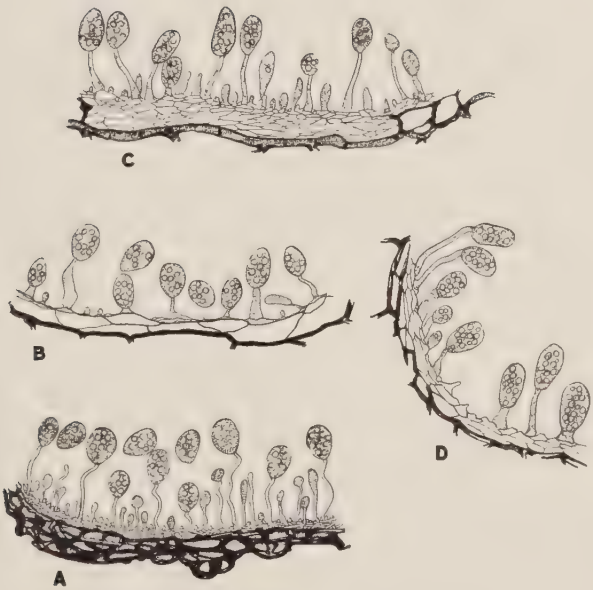

PLATE 2.—SECTIONS THRU PYCNIDIA FROM DIFFERENT ORGANS OF THE HOST SHOWING THE SPOROGENOUS LAYER

(A) From the leaves (blades); (B) from the petioles; (C) from the fruit; (D) from the advancing area of the canker.

It is evident that the species at present in the genera Phoma and Phyllosticta should be critically examined in order to segregate them into several genera on morphological grounds.

In 1916 Sydow[91] created the genus Phyllostictina based on the type *Phyllostictina murrayae* Syd., occurring on living leaves of *Murrayae koenigii,* from Dehra Dun, India.

Von Höhnel[48] later studied the type specimen of *Phyllostictina murrayae* Syd., and contends that its characters closely agree with those of *Phoma uvicola* B. & C., and comments that he found no trace of conidiophores altho he assumes that they were originally present and had dissolved. He claims that both of these fungi belong to the same form genus and to receive them he emends the description of the genus Phyllostictina.

Professor Sydow furnished the writer with type specimens of *Phyllostictina murrayae* for study. The outstanding characters are the globose pycnidia with dark brown, thin parenchyma-like walls composed of two layers of thin-walled cells, with usually a definite ostiole surrounded by a slightly thickened ring of wall cells. The spores are ovate, or broadly elliptical, and contain numerous, uniform round globules. From microtome sections of the specimen these spores appear to be formed by the histolysis of the gelatinous parenchymatous context, without conidiophores.

Phyllosticta solitaria is certainly not a typical Phyllosticta and also cannot be regarded as a Phyllostictina since it does not agree with the type nor with the original description altho it does agree with the emended description of von Höhnel. It is evident that von Höhnel's emended description is applicable to *Phoma uvicola* and to *Phyllosticta solitaria* but not to *Phyllostictina murrayae.* It is the belief of von Höhnel that all forms similar to *Phoma uvicola* are the conidial stages of Guignardia which indeed has been found to be true of *Phyllosticta paviae* Desm. (*Guignardia aesculi* (Pk.) Stewart) and of the imperfect form of *Guignardia vaccinii* Shear, lately named *Phyllostictina vaccinii* Shear.[85] It is also probable that *Phyllosticta solitaria* E. & E., *Phyllosticta congesta* Heald and Wolf and other forms like *Phoma uvicola* are related to Guignardia. Shear,[85] however, adhering to the view of von Höhnel, has regarded *Phyllosticta solitaria* E. & E. as a good Phyllostictina. Roberts'[70] study of *Phyllosticta congesta* Heald and Wolf shows the very close relation of this fungus with *P. solitaria* E. & E.

In *Phoma uvicola* and *Phyllosticta solitaria* the conidiophores are always present (Fig. 6). The pycnidial membrane of both of these forms is similar altho variable; occasionally thin, and at times thickened laterally or only in the region of the ostiole. The pycnosclerotia are often somewhat stromatic and always have thick, dense dothid-

caceous membranes. Their mode of spore formation differs so much from our present conception of the genus Phyllosticta that these forms might rightfully be established under a new form genus in the main like the emended description of Phyllostictina. The presence of a gelatinous cap or appendage on the spores of the pycnosclerotia of these species is a character of added value for supporting the segregation.

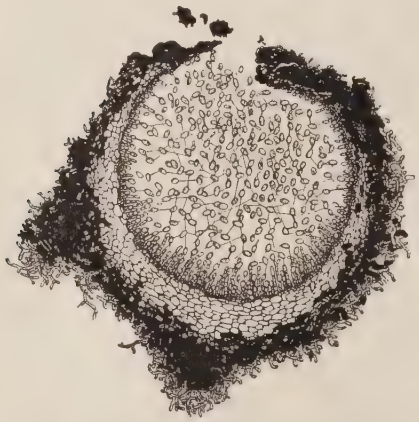

FIG. 6.—SECTION THRU A PYCNOSCLEROTIUM FROM CULTURE
Note gelatinous threads connecting spores

The question therefore arises whether to create a new genus for *Phoma uvicola* B. & C. (not *Phyllostictina uvicola* (B. & C.) v. Höhnel) and *Phyllosticta solitaria* E. & E., embodying the essential characters of the emended description of Phyllostictina as given by von Höhnel, or to retain these forms in the form genera Phoma and Phyllosticta until critical examination of the species in these and other related genera is possible. The latter course appears to be advisable; therefore, for the present, the original name *Phyllosticta solitaria* E. & E. has been retained.

PHYSIOLOGY

Cultural Characters

Phyllosticta solitaria grows readily upon almost any type of artificial media, but it grows well upon a medium rich in carbohydrates. In the study of the cultural characters of the fungus, the following types of media were employed: apple-bark corn-meal agar, Czapek's agar, apple agar, apple corn-meal agar, corn-meal agar, prune agar, sterile apple twigs, apple-bark agar, oat agar.

Apple agar was prepared by heating 150 grams of chopped apples in distilled water in a boiling water bath for thirty minutes, then filtering and adding to the filtrate 20 grams of granulated sugar. The volume was made up to 1,000 cc. and 20 grams of agar added. Apple-bark agar was prepared similarly; the cortex of water sprouts and petioles, and leaves being employed in the preparation of the mixture. Combinations of these media were prepared by mixing together equal parts of separate media. The other types of media were prepared according to standard formulae.

Growth is manifested as a spreading, flat, white, round colony, growing superficially upon the medium and only slightly penetrating it (Fig. 7). The colony may advance evenly in all directions, or in a wavy-bordered fashion. An olivaceous coloration appears very early in the center of the colony, and increases in area with the increase in area of the colony. On oat agar, and frequently on corn-meal agar, the olivaceous coloration fails to appear. Growth is commonly olivaceous and with age becomes black-olivaceous and almost com

FIG. 7.—APPLE BLOTCH FUNGUS IN CULTURE
Note the flat, spreading character of the growth and the numerous black pycnosclerotia. Growing on apple agar at 25° C. in Petri dish.

pletely black in the interior. With the appearance of the dark olivaceous coloration in the center and the light olivaceous coloration about the center, the colony becomes over-grown by a short, floccose, erect, and olivaceous aerial growth, arising first in the center of the colony and advancing outward.

The production of pycnosclerotia (Fig. 8) occurs upon almost all types of artificial media. Apple agars, sterile apple twigs, prune agar, and Czapek's agar, are very favorable for their production. Carbonaceous, coal-black pycnosclerotia form over the entire inner surface of the colony giving the surface a crusty, coal-black appearance (Plate 3).

On Czapek's agar, prune agar, and commonly on apple agar, the fungous growth eventually becomes a high, irregular, carbonaceous

mass of mycelium and pycnosclerotia. This type of growth appears commonly on agar slants on the above types of media, but rarely in plates on these media excepting on Czapek's medium on which the colony always grows in a high, irregular fashion. On corn-meal or oat agar, on the other hand, growth is always flat and spreading.

Factors Involved in Growth and Pycnosclerotia Formation

In the experiment dealing with the relation of temperature and light on growth and pycnosclerotia formation various types of media, previously mentioned, were employed. The organism was transferred to agar plates and tubes, and placed in the open in constant temperature chambers of 5°, 10°, 15°, 20°, 25°, and 30° C. An equal number of plates and tubes of each medium were placed in black, cardboard, light-proof boxes, consisting of box and lid which permitted of easy

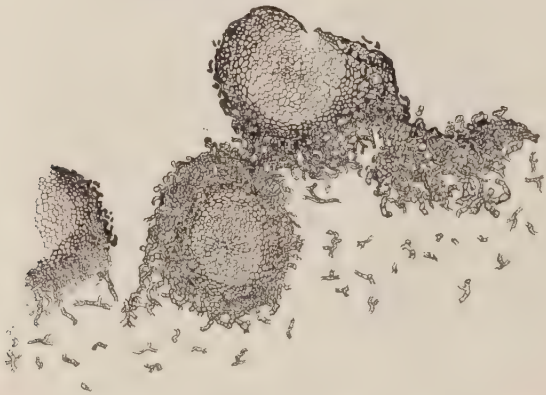

FIG. 8.—SECTION THRU PYCNOSCLEROTIA FROM CULTURE
Note character of the pseudo-parenchymatous interior and thick outer coat.

aeration. These temperature chambers were located in greenhouses and protected against direct sunlight. Constant temperatures were maintained by the circulation of brine, cooled by the expansion of sulfur dioxid. The brine was circulated thru the chambers by an electrically driven pump, and the temperatures were kept constant and uniform in the chambers by thermostats and electrically driven fans. The humidity factor was not under control, but since the differences in growth and production of pycnosclerotia were apparent long before any drying of the media occurred, the effect of different temperatures on growth and pycnosclerotia formation may be regarded as relatively accurate.

The results obtained from this study bear evidence that growth and pycnosclerotia formation of *Phyllosticta solitaria* are not affected

PLATE 3.—CULTURES OF *P. solitaria*, SHOWING TYPE AND MANNER OF GROWTH ON DIFFERENT SOLID MEDIA AND THE BLACK, CARBONACEOUS PYCNOSCLEROTIA

Tube 17, on Czapek and prune agar mixed; 20, on Czapek and apple-bark agar mixed; 21, 22, on apple agar; 23, 24, on apple-fruit and apple-bark agar mixed; 25, 26, on Czapek and apple-fruit agar mixed.

TABLE 1.—INFLUENCE OF DIFFERENT TEMPERATURES UPON THE RATE OF APPEARANCE OF GROWTH IN OPEN AND IN LIGHT-PROOF BOXES

Temperature	5°C.	10°C.	15°C.	20°C.	25°C.	30°C.	35°C.
	Number of days after planting						
Open boxes	No growth	25–30	10–15	4	3	3	No growth
Light-proof boxes	No growth	30–35	10–12	4	2–3	2–3	No growth

TABLE 2.—INFLUENCE OF DIFFERENT TEMPERATURES UPON THE RATE OF PYCNOSCLEROTIA PRODUCTION IN OPEN AND IN LIGHT-PROOF BOXES

Temperature	5°C.	10°C.	15°C.	20°C.	25°C.	30°C.	35°C.
	Number of days after planting						
Open boxes	No growth	30–35	23	13	5–10	5–7	No growth
Light-proof boxes	No growth	30–40	18–25	11–13	5–8	5–8	No growth

by light. The colonies on agar plates and tube slants in the open, and in the light-proof boxes, from all appearances developed and produced pycnosclerotia at the same time. There was no evidence to show that constant darkness had a repressive effect upon growth or pycnosclerotia formation. According to Coons[18] light is a decisive factor in the reproduction of *Plenodomus fuscomaculans* regardless of the richness or poverty of the substrata in nutrients. With that organism there is also a strong tendency for increased growth in the dark. The results of Coons and Levine[19] and Levine[20] indicate that among the genera of Sphaeropsidales many species are definitely light positive to pycnidia formation while many are indifferent, producing pycnidia under all conditions. Their results also show that the species of one form-genus do not necessarily behave alike. *Phyllosticta solitaria* may be classed among those species which are indifferent to light.

The constant presence of pycnidia on the upper sides of the leaf blades is not due to any light reaction, but, as histological studies show, to the construction of the leaf and the supply of food. The organism grows and fruits as well in the cavities of the apple, on the pedicels, and on the bud scales, as elsewhere on the host. These tissues are shaded much more than are other parts of the host, yet fruiting does not seem to be affected.

The relation of temperature to growth and pycnosclerotia formation is significant (Tables 1 and 2). At 5° C. growth is completely suppressed. At 10° C. growth is very slow and does not become perceptible on the surface of agar until twenty-five to thirty-five days after planting; the first pycnosclerotia are apparent from thirty to forty days after planting. At 15° C. the organism grows slowly altho better than at 10° C.; the earliest apparent growth is between ten and fifteen days after planting. At 20° C., growth is manifested in

four days and the pycnosclerotia are apparent in eleven to thirteen days.

The optimum temperature for growth and pycnosclerotia formation lies between 25° and 30° C., 25° C. being slightly more favorable than 30° C. At both temperatures growth is evident in two to three days and pycnosclerotia formation in five to eight days after planting. At 35° C. the fungus does not grow, showing that the maximum temperature for growth lies between 30° C. and 35° C. (Table 1).

Results show that pycnosclerotia production occurs at all temperatures favorable to growth, and that where growth is slow the formation of pycnosclerotia is slow. At the extreme temperatures pycnosclerotia production is less in proportion to growth than at the more favorable temperatures, which indicates that growth of *P. solitaria* occurs at slightly wider limits than the production of pycnosclerotia.

Thruout this study it was evident that corn-meal and oat agars, i.e., media rich in protein, were not favorable for pycnosclerotia production, whereas all of the other media employed induced them abundantly.

Spore Production in Culture

In spite of the rich masses of pycnosclerotia formed on artificial media spores were rarely produced. In regard to spore formation of *P. solitaria* Clinton[17] states: "Cultures made by taking diseased tissues from the interior of affected apples produced a characteristic dark olive-green mycelium that formed patches of rather slow growth on the medium and had not, after two months development, given any sign of the formation of a spore stage." Scott and Rorer[79] remark. "The fungus does not fruit freely on culture media, and so far, the writers have been able to secure spore-bearing pycnidia only on sterilized apple wood and corn meal agar. Pycnidia-like bodies are formed in great abundance on all media, but these are, for the most part, sterile. In apple-wood cultures, the fungus generally fruits well, producing little groups of pycnidia rich in spores." Lewis[51] says, "No spores were produced on prune or potato agar or on potato cylinders, but apple wood cultures produced spores abundantly." Roberts[67] states in a discussion of cultural relations of the blotch fungus, "*Phyllosticta solitaria* will produce pycnidia on all of the ordinary solid culture media. These pycnidia, however, do not produce spores." He was able to grow the fungus with the formation of both pycnidia and spores only on sterile apple wood, and even on this medium, two to three months elapsed before mature spores were produced. Stewart[89] working with *Guignardia aesculi* found that cultures from ascospores and from diseased horse chestnut leaves developed small sclerotia-like bodies and "altho the fungus from these two sources was cultured for a period of twelve months on various media no fruiting bodies ever developed."

The writer cultured the organism repeatedly on different media and under various conditions. Pycnosclerotia production always occurred, but spore production could never be expected, or predicted with any measure of certainty. The pycnosclerotia were examined for spores at short intervals for a period of two months. Spores were very rarely found. In 1919 the writer secured spores on a corn-meal agar slant at 25° C. in seven days from the date of planting. A few pycnosclerotia formed on the colony, but on sectioning them, it was found that only a few contained spores and that the remainder were sterile. During this study spore production occurred a few times—on one occasion at 30° C. in plates on a mixture of Czapek's and apple media and again at 25° C. on oat agar. It occurred about twenty-six days after planting and the medium then was completely dry and hardened.

In February, 1921, the fungus was isolated from cankers on variously aged bark and transferred to tubes of a mixture of Czapek's and apple agar, and to corn-meal agar containing prune juice. Spore production occurred abundantly in several of these cultures. The age of the canker and season of the year in which the isolations were made seemed, at that time, to have some influence upon spore bearing. In the earlier cultural studies most of the isolations from the host lesions were made in autumn and winter while the organism was in an inactive condition, but no spore-bearing cultures were obtained. Further attempts early in the season in later years and in the spring of 1923, with mycelium from old cankers on the same medium and under the same conditions failed to obtain fertile pycnidia.

Since it is a common biologic principle that suppression in growth generally leads to reproduction, the writer grew the organism on media in "roll cultures." The "roll cultures" were prepared by rapidly rolling tubes containing 10cc. of warm medium in a vertical position between the palms of the hands with the base of the tube in cold water. In such tubes the medium is shallow, and consequently the mycelium, by coming in direct contact with the glass wall of the culture tube, would eventually become starved, a condition which would suppress growth and affect fruiting. The "roll cultures," however, did not induce spore production, but the production of pycnosclerotia was as common as usual.

Repeated attempts were made to obtain sporulation by subjecting the pycnosclerotia to alternating high and low temperatures (freezing them and restoring them to warm temperature). The results, however, were all negative. Spores were obtained abundantly only once in pure culture, and then under the fluctuating conditions of a laboratory. The factors favorable to sporulation in culture remain unknown.

There is no evidence of spore-bearing strains in culture. The spore-bearing cultures obtained by the writer have never given rise to others,

altho the same medium was used and the organism was incubated in the same laboratory.

Spore Germination

Germination (Fig. 9) is first manifested by a small, round protuberance occurring most commonly on the narrow end of the spore.

FIG. 9.—COMPARATIVE DEVELOPMENT OF TUBES OF GERMINATING SPORES AT THE END OF FORTY-EIGHT HOURS AT CONSTANT TEMPERATURES

(A) Mature spores at 10° C., (A_1) immature spores bearing conspicuous gelatinous cap, (B) at 15° C., (C) at 20° C., (D) at 25° C., (E) at 30° C.

In practically 85 percent of the germinations the germ tube arises from the narrow pole, about 10 percent arise from the sides of the spore, and the remaining 5 percent or less arise from the broad pole.

The broad pole of the spore bears the gelatinous appendage which evidently serves to attach the spore to the substratum it is capable of infecting. The primary germ tube issues usually from the opposite end. In the course of time a second germ tube arises commonly from the broad end of the spore. The cap or appendage is eventually dissolved; it is inconspicuous on mature spores.

In contrast to the successful germination of spores from culture, the spores from natural sources have never been induced to germinate regularly or in any large quantity. During the spring and summer of 1920 and 1921, from April 15 to July 15, repeated attempts were made to germinate spores secured from pycnidia on leaves, fruit, and bark. The pycnidia were crushed in sterile, tap, or rainwater, and drops of the suspension were placed on slides in moist Petri dishes and kept at room temperature. Similar mounts to which crushed pieces of apple peelings, leaves, or bark were added were made during the spring and summer of 1920 and 1921, in the hope that these might in some way facilitate spore germination. The percentages of germination were small, irregular, and generally insignificant. Occasional mounts showed a trace of germination and rarely high percentages of germination, but since the conditions under which the high percentages of germination occurred were the same in all respects as those where none occurred, it is difficult to explain the failures. Roberts[67] tested the germination of spores of *P. solitaria* from bark cankers and obtained germination in distilled water after May 23, 1914. On May 13, 1915, he found that 10 percent, and after May 24, 75 percent had germinated.

The conditions necessary for spore germination are moisture, nutrition, favorable temperatures, and maturity of the spores. Sterile distilled water is not a favorable medium for vigorous and successful germination since the germ tubes grow slowly to about three to four times the length of the spore and then collapse from want of nutrient. In sterile distilled water the percentage of germination is small; in sterile tap water it may reach 100 percent. In a weak solution of apple or prune extract, the germ tubes appear early and grow vigorously, and finally give rise to mycelium.

The spores do not germinate well unless they are fully matured. This is shown by attempts to germinate spores from natural sources before the occurrence of natural infection, or from pycnidia from the outer living portions of the cankers, even after primary infection has taken place. Spores formed in the pycnosclerotia on the overwintered cankers require about three to four months to mature, that is, from the time differentiation begins to time of spore-discharge. Spores from young spore-bearing cultures fail to germinate even in a nutrient medium at the optimum temperatures. The best germination was ob-

tained from spore-bearing cultures one to one and one-half months old. From a culture sixteen days old the germination was less than 1 percent under the most favorable conditions. Spores from a culture forty-six days old under similar conditions gave 100 percent germination.

In spore germination the temperature is of extreme importance. Pycnidia were taken from fertile cultures and crushed in sterile distilled water, or in a weak, sterilized, nutrient solution, such as prune or apple fruit extract, and the volume of the liquid was then increased five to ten times in order to avoid crowding the spores. The prune extract was prepared by cooking two or three prunes in 200 cc. of distilled water; the apple extract was made similarly from fresh apples. The extracts were filtered and sterilized before using. The spores were germinated on slides in Petri dishes at constant tempera-

TABLE 3.—RATE AND PERCENTAGE OF GERMINATION, AT DIFFERENT TEMPERATURES, OF SPORES FROM CULTURE 32 DAYS OLD

Spores suspended in a weak sterilized solution of apple extract

Hours after sowing.....	10	20	32	45	70	95	117
Temperature	Percentage germination						
41°F. : 5°C.....	0	0	0	0	0	t	t
50°F. : 10°C.....	0	t	t	1	1	5–10	10
58°F. : 15°C.....	t	1	1–5	5	10–15	20	20–25
68°F. : 20°C.....	1	2–3	15–20	20	50	50	50
77°F. : 25°C.....	2	5	25	30	50	50–60	50–60
86°F. : 30°C.....	0	1	1	1	(Practically no germination)		

t = trace.

tures. Drops of the spore suspension were placed on slides and two slides were placed in each dish on glass rods with moistened filter paper in the bottom of the dish with sufficient water to maintain moist conditions.

The results in Table 3 are based on spores from a culture thirty-two days old. The percentage of germination is not high, evidently owing to the immaturity of the spores. After an exposure of 167 hours, the Petri dishes in the 5°, 10°, and 15° C. chambers were transferred to the 20° C. chamber where, within 132 hours, 40 to 60 percent of the spores had germinated and developed hyphae.

The results in Table 4 were obtained with spores from a culture forty-six days old. They show that with this increased age of the pycnidia there was increased percentage of germination. At 15°, 20°, 25°, and 30° C., 100 percent germination was eventually present, but the rate of development of the germ tubes was most extensive and rapid at 25° and 30° C. After an exposure of 101 hours at 5° and 10° C. the Petri dishes were placed in the 25° C. chamber, where at the end of thirteen hours about 80 percent of the spores had germinated, and at the end of twenty-five hours from 80 to 100 percent.

TABLE 4.—RATE AND PERCENTAGE OF GERMINATION, AT DIFFERENT TEMPERATURES, OF SPORES FROM CULTURE 46 DAYS OLD

Spores suspended in a weak sterilized solution of apple extract

Hours after sowing	7	17	31	42	73
Temperature	Percentage germination				
41°F. : 5°C	0	0	0	0	0
50°F. : 10°C	0	0	t	t	t
59°F. : 15°C	0	3	30–40	80	90–100
68°F. : 20°C	0	40–50	90–95	95–100	100
77°F. : 25°C	t	95	95–100	(Excellent germination)	
86°F. : 30°C	30–40	90–100	95–100	(Excellent germination)	

t = trace.

The results in Table 5 are based on spores from a culture thirty-four days old. The spores were suspended in sterile distilled water. The germination was low at first, altho it increased later even at the lower temperatures. The growth of the germ tubes was checked early. After 132 hours the Petri dishes in the 5° C. chamber were transferred to the 20° C. chamber and good germination resulted, altho the germ tubes were poorly developed.

TABLE 5.—RATE AND PERCENTAGE OF GERMINATION, AT DIFFERENT TEMPERATURES, OF SPORES FROM CULTURE 34 DAYS OLD

Spores suspended in sterile distilled water

Hours after sowing	12	21	35	59	108
Temperature	Percentage germination				
41°F. : 5°C	0	0	0	0	0
50°F. : 10°C	0	0	t	t	t
59°F. : 15°C	t	t	1–2	20–30	25–30
68°F. : 20°C	t	1	10	30	30–40
77°F. : 25°C	1	10	15	30–40	40–50
86°F. : 30°C	2–4	50	50	50	60

t = trace.

In Table 6 the mounts were made from a culture forty-eight days old. Petri dishes exposed to 5°, 10°, and 15° C. respectively for seventy-one hours were transferred to 25° C. and at the end of fourteen hours some germination had occurred at 5° C., and 50 to 60 per cent at 10° and 15° C.

In Table 7 the germinations were conducted in a laboratory where the temperatures fluctuated between 13° and 24° C. The spores were from a culture thirty-four days old.

The data in the above tables show that the optimum temperature for spore germination lies around 30° C. (86° F.), and that the rate of growth of the germ tubes is greatest at 25° C. (77° F.) and 30° C. (86° F.). At the lower temperatures, namely 15° C. (59° F.)

TABLE 6.—RATE AND PERCENTAGE OF GERMINATION, AT DIFFERENT TEMPERATURES, OF SPORES FROM CULTURE 48 DAYS OLD

Spores suspended in sterile distilled water

Hours after sowing	11	17	34	46	71
Temperature	Percentage germination				
41°F. : 5°C.	0	0	0	0	0
50°F. : 10°C.	0	0	0	0	0
59°F. : 15°C.	0	0	t	t	t
68°F. : 20°C.	0	0	30–40	40	40–50
77°F. : 25°C.	0	30	50–60	60–70	60–70
86°F. : 30°C.	5–10	40–50	60–70	60–70	70

TABLE 7.—RATE AND PERCENTAGE OF GERMINATION, UNDER LABORATORY TEMPERATURES, OF SPORES FROM CULTURE 34 DAYS OLD

Hours after sowing	12	24	36	60
Media used	Percentage germination			
Sterile water	t	50	50	95
Weak sugar solution	t	60	70–90	100
Apple-bark extract	0	0	2–10	25–35
Apple fruit juice	t	90	100	100

t = trace.

and 20° C. (68° F.), the amount of germination at first is small and the growth of the germ tubes is slow, altho with longer exposures 100 percent germination is obtained in nutrient solutions, including sterile tap water (Fig. 9, B and C). At 15° C. (59 F.) branching and anastomosing of the germ tubes are rare, while at 20° C. (68° F.), altho growth is slow, hyphae ultimately appear. At 5° C. (41° F.) and 10° C. (50° F.) germination rarely occurs and then growth never exceeds twice the length of the spore (Fig. 9, A).

The spores remain viable in moisture for some time under temperatures low enough to inhibit germination. Since spores from pure culture were rarely obtained, no studies could be undertaken to determine the longevity of the spores under various conditions; however, the above results show that when spores are exposed to a temperature of 5° C. (41° F.) for one week they remain viable and germinate normally when introduced into higher temperatures. Undoubtedly the spores can survive much longer periods under these conditions. This is significant since under natural conditions in prolonged periods of rain and low temperatures spores may remain viable and produce infection when favorable temperatures are obtained.

LIFE HISTORY

Inoculation and Infection

Scott and Rorer[79] report the successful infection of the leaves and fruit of the apple with spores obtained from bark cankers and apple blotches. Numerous small blotches were found on the fruits, leaf blades, and petioles in one month, but no bark cankers resulted. One tree which was atomized with sterile water as a check showed no signs of the disease. The experiment of Scott and Rorer is far from conclusive since they report the results of but a single experiment without the use of pure culture and in a territory where blotch was seriously prevalent.

Roberts[67] infected successfully the foliage, fruits, and twigs of the Missouri Pippin with spores of *Phyllosticta solitaria* obtained from pure culture. The spores were suspended in sterile water and sprayed upon the host in early July. The disease appeared a month later. His attempts to infect the fruit of the Missouri Pippin and Ben Davis after August 1 were unsuccessful. Roberts[68] states, "Infection can take place only on the young branches of the current year's growth. Vigorously growing water sprouts are especially susceptible."

The writer has been unsuccessful in securing artificial infection. In the winter of 1921 spores were obtained abundantly on artificial media and when properly matured, as indicated by the high percentages of germination, they were suspended in water, sprayed with an atomizer, and sprinkled on potted one-year-old Duchess apple trees in inoculating chambers. The trees were grown in the greenhouse for a month or more and the foliage was abundant. Clusters of leaves were also atomized and enclosed in transparent parchment paper bags. In each sack moist, absorbent cotton was placed in order to insure moist conditions. All such attempts were unsuccessful. The failure to obtain spores in quantity in pure culture eliminated all hope of conducting artificial inoculations with spores under aseptic conditions.

During two seasons' work in southern Illinois, many attempts were made to produce the disease artificially with spores obtained from host lesions. One-year-old Duchess trees were secured from a northern nursery and planted in pots. Pycnidia were crushed in sterile water, tap water, or rain water, and the spore suspension was applied to the new growth with an atomizer. Transparent parchment paper bags containing moist cotton were then placed over the atomized foliage and the bags were moistened frequently. Despite the many attempts no infections resulted.

Similar efforts were made to infect the healthy fruit and foliage of bearing Duchess and Benoni trees with spores obtained from natural sources. Before natural infection occurred transparent parch-

ment paper bags were placed over and tied around the new growth of foliage and fruit as a protection against natural infection. Frequently, thruout the season, some of the bags were removed and the healthy growth atomized with a water suspension of spores, this being done when possible before rains and in the evening. After atomization a handful of wet absorbent cotton was placed around the stem and the growth was covered by a fresh bag, and moistened. For every group of protected growths atomized with spores, two or three bagged growths were atomized with sterile water to serve as checks. Similar trials were made using glass flasks and chimneys containing moist cotton in place of the parchment paper bags. Infections were never obtained.

The difficulty of securing spores in pure culture and artificially infecting the host likewise has been encountered with *Guignardia bidwellii, G. aesculi,* and *G. vaccinii.* Reddick[66] was unable to obtain successful infections of the grape with pycnospores of *Guignardia bidwellii;* he states, "The writer is utterly at a loss to understand his failures to obtain infections." Shear[84] was unable to infect the cranberry artificially to thereby discover exactly when and in what manner infection of the leaves and fruit takes place. He found that the majority of cultures of *Guignardia vaccinii* were either entirely sterile or produced only pycnosclerotia.

Sources of Inoculum

The fruiting bodies in the central areas of the cankers are matured and free of spores earlier in the season than those in the outer areas. Primary infections, therefore, are evidently the result of spores from pycnosclerotia confined to the older areas of the canker, the pycnidia on the outer areas serving as sources of inoculum for later infections. Owing to the slow advance of the cankers during the late spring and summer, inoculum from the cankers during the season is practically limited to the fruiting bodies formed prior to the fall of the bloom. The irregular and continued discharge of spores from the pycnidia on the cankers is responsible for repeated infections thruout the spring and summer. After August, infections from these sources cease, for the supply of spores becomes exhausted and only pycnosclerotia are formed. The new cankers, which appear in August, likewise bear only pycnosclerotia which function the following spring.

After leaf petioles, blades, pedicels, and fruit are infected, the sources of inoculum later in the season are naturally increased many times. The pycnospores from the lesions on the leaves infect the same leaves and, as new lesions appear on the fruit and leaves, new sources of inoculum arise. Infections resulting from inoculum from these

sources cease in August, since the supply of spores becomes exhausted, and the organism produces only pycnosclerotia.

The pycnosclerotia also overwinter on the mummies and fallen leaves. In the spring these pycnosclerotia either remain sterile or produce pycnospores, but in the absence of evidence, the significance of these spores is uncertain. In view of the location of mummied fruit and decaying leaves, and the adhesive quality of the spores when exuded under moist conditions it would seem that the influence of gravity and washings from rain would carry the spores away from the action of wind and a favorable substratum.

The relation of the location of diseased fruit and foliage to the location of the cankers supports the view that the inocula causing primary infections arise from the bark cankers. This relationship is best observed on lightly infected trees. With the first appearance of the disease on the leaves and fruit, close observations show that the first symptoms of the disease are always close to, and associated with, the bark cankers. A very clear case of such a relationship was found at Mount Morris (Ill.) in 1920. On only one tree in a Northwestern Greening orchard, did the writer find a cluster of blotched apples on a spur, accompanied by infected leaves. A lone canker was on a branch directly above. In no instance has it been possible to trace primary infections to any source but the cankers, a fact which is universally recognized in the literature on this disease.

Time of Infection

The periods of infection have been studied for three years at various localities in Illinois. The plan involved the daily presence of the writer in the orchard under observation, bagging of fruit and foliage, compilation of daily weather data, spraying, and other orchard operations. The results obtained with bags correlated with weather data have made it possible to arrive at valuable information regarding the dates of primary infection and the frequency of infections during the season.

The bags were of white, stiff, transparent, parchment paper bearing a disk at the upper end to which a string was attached for tying. Two sizes were employed, 7½ by 5¼ inches for the fruit, and 14½ by 8 inches for water sprouts and terminal twig growth. When the bags were first used it was found that often in rainy weather the glued edges came apart. An application of hot paraffin to the edges of the bags before use insured their security during rainy weather.

The bagging operations were conducted as follows: A few days after petal fall, in dry, fair weather, several bags were tied over the fruit and twigs of severely cankered trees. At regular intervals thereafter, until the first symptoms of the disease on the fruit and foliage became apparent, additional bags were placed on other fruits

and twigs. Likewise, at regular intervals, bags were removed during the course of the season tho many bags were left on until September to serve as checks. But one apple and a few leaves were limited to

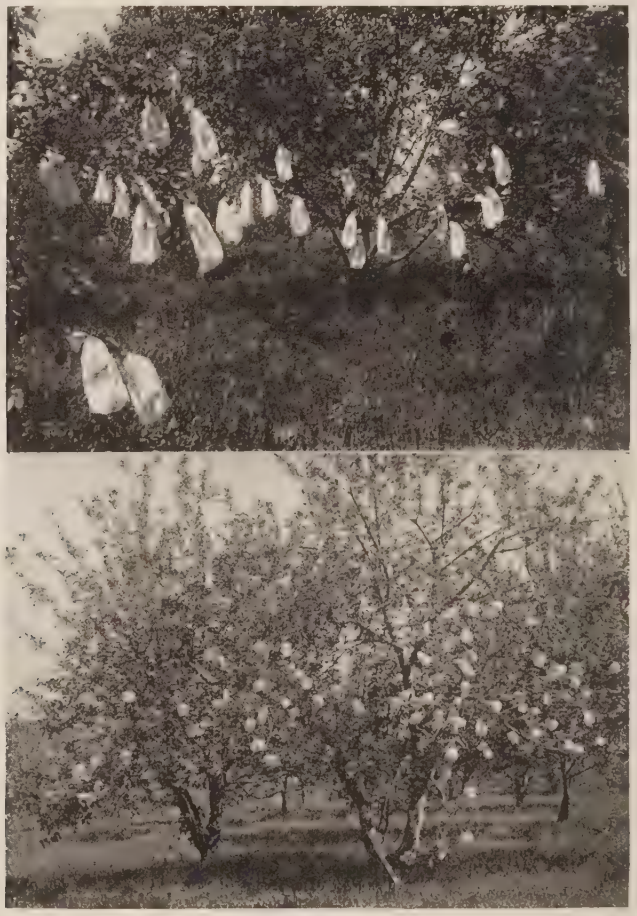

FIG. 10.—BAGS USED TO DETERMINE TIME AND DURATION OF NATURAL INFECTION

Above, on Duchess trees; below, on Sops of Wine trees. Anna, May, 1921.

a single small bag. When more than one apple was present on the spur the others were removed, thus allowing for the better development of the apple and avoiding the danger of breaking the bag. The larger bags allowed covering of entire fruit clusters. To facilitate

placing and tying the bag about the fruit and twigs, the leaves on a few of the nodes of the preceding season's growth were removed. Because of the stiffness of the parchment paper when dry, tearing cannot be avoided in opening and tying unless the bag is first moistened. A short wetting before opening and tying permits of firm tying about the twig and thus avoids any danger of infection enter-

FIG. 11.—COMPARATIVE SIZE OF FOUR SUSCEPTIBLE VARIETIES OF APPLES AT THE TIME OF FIRST HEAVY INFECTIONS AT ANNA, 1921

Upper left, Duchess; upper right, Sops of Wine; lower left, Ben Davis; lower right, Benoni.

ing the bag at this point. The bag is placed over the growth and the upper portion is gathered together and wrapped evenly about the twig, and the string is wrapped a few times below the disk, then at the base of the new growth and a few times about the disk. The tyings must not be too tight and care must be taken to exclude any portion of the previous season's growth, since the presence of cankers in the bag would destroy the value of the experiment. On drying, the bags become stiff and if the tying is done properly, growth proceeds as with the unbagged fruit (Fig. 10). The protected fruit

matures somewhat earlier than the unbagged fruit, but this does not vitiate the accuracy of the data since infection is possible even when the fruit and foliage are nearly mature.

Season of 1920 at Anna.—The bagging was conducted on the Duchess variety (Table 8). The first bags were put on May 1 and 2. Petal fall (75 percent fallen) occurred on April 25 and 26 and the calyx spray was applied on April 26 and 27. The first infections of the season occurred during the rains of May 11, 12, and 13, or fifteen to eighteen days after the recorded period of petal fall. Further infections occurred during the rains of May 16, 17, and 18, May 30

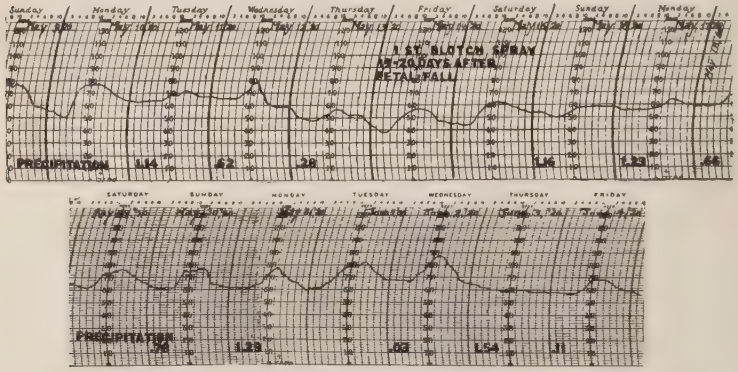

FIG. 12.—THERMOGRAPH AND PRECIPITATION RECORDS IN ANDERSON ORCHARD, ANNA, MAY 9 TO 17, AND MAY 29 TO JUNE 4, 1920

Time periods for Duchess variety; precipitation for twenty-four hour period, evening to evening.

and 31, and June 3. The first spray for blotch was applied on May 14 and 15, and spraying was continued at weekly intervals during May and June. The failure to apply the first blotch spray ahead of the rainy period of May 11 to 13 resulted in poor control in every plat. In bags that were put on May 12 and 13, and removed on June 11, there was present, with one exception, an abundance of fruit and petiole infection. This shows that primary infections occurred between May 2 and May 14, and from a study of the local weather records (Fig. 12) the primary infection of Duchess fruit and foliage must have occurred on May 11, 12, and 13. The disease was found on May 27 for the first time in the season.

The data show (Table 8) that the disease was not present on foliage protected up to June 4, when examined on July 15. However, growth protected up to June 4 and examined on September 11, revealed serious infection of the petioles. Study of the weather after June 4 shows that small precipitations occurred on June 19, 21, 22, July 2, 5, and that heavy rain occurred on July 13 and July 18. Since two to

TABLE 8.—RESULTS OF BAGGING EXPERIMENTS ON DUCHESS TREES, ANDERSON ORCHARD, ANNA, 1920

No. of bags	Date put on	Date taken off	Infection	Second examination	
				Date	Infection
5	May 1 and 2	June 4	—	July 15	—
7	"	"	—	Sept. 11	S.p.i.
1	"	"	—	"	M.p.i.
3	"	June 6	—	July 15	—
7	"	"	—	Sept. 11	S.p.i.
1	"	"	—	"	—
5	"	June 8	—	July 15	—
3	"	"	—	Sept. 11	S.p.i.
3	"	"	—	"	M.p.i.
1	"	"	—		
5	"	June 11	—	July 15	—
2	"	"	—	Sept. 11	—
6	"	"	—	"	S.p.i.
5	"	June 16	—	July 15	—
5	"	"	—	Sept. 11	S.p.i.
5	"	June 20	—	July 15	—
5	"	"	—	Sept. 11	S.p.i.
5	"	June 25	—	July 15	—
2	"	"	—	Sept. 11	—
5	"	"	—	"	S.p.i.
2	"	July 2	—	"	S.p.i.
5	"	"	—	"	—
5	"	July 9	—	"	S.p.i.
3	"	"	—	"	—
2	"	July 13	—	"	S.p.i.
1	"	"	—	"	M.p.i.
1	"	"	—	"	—
20 (checks)	"	Sept. 11	Found in 1 bag		
8	"	July 2	—	July 15	—
4	May 12	June 11	S.f. & p.i.		
1	"	"	—		
3	May 13	"	S.f. & p.i.		
3	May 14	"	S.f. & p.i.		
1	"	"	—		
3	May 17	"	S.f. & p.i.		
1	"	"	S. p. i.		
6	May 21	"	S.f. & p.i.		
1	"	"	—		
6	May 23	"	S.f. & p.i.		

(—) = disease not present; S.p.i. = severe petiole infection; M.p.i. = moderate petiole infection; S.f. & p.i. = severe fruit and petiole infection.

three weeks are required for the symptoms to become apparent on fruit and foliage, it seems that the small precipitations between June 4 and July 15 were insignificant and not favorable for infection. The precipitations of July 13 and 18 were large enough for infection, and the constancy of the disease on the foliage when examined on September 11 indicates that infection occurred during these rains, as well as during the heavy rains of August 8 to 10 and 15. The remaining days of these two months were marked by dry weather and occasional short rains unfavorable for infection. When the bags were removed at intervals during the period June 4 to July 13, and the fruit and foliage examined on July 15, the disease was universally absent, and when this same growth was examined on September 11, the disease, with a few exceptions, was universally present. Heavy infections, therefore, occurred during July and August.

Season of 1921 at Anna.—The bagging experiments in this season were conducted on the Duchess variety (Table 9). The season was

TABLE 9.—RESULTS OF BAGGING EXPERIMENTS ON DUCHESS TREES, MILLER ORCHARD, ANNA, 1921

No. of bags	Date put on	Date taken off	Infection	Second examination		Third examination	
				Date	Infection	Date	Infection
2	April 18	May 23	—	Sept. 7	S.p.i.		
2	"	"	—	July 15	"		
3	"	May 25	—	"	"		
2	"	May 28	—	"	"		
1	"	"	—	"	M.p.i.	Sept. 7	S.p.i
4	"	May 31	—	"	S.p.i.		
1	"	"	—	Sept. 7	"		
4	"	June 4	—	July 15	"		
1	"	"	—	"	M.p.i	"	M.p.i.
1	"	June 10	—	"	S.p.i.	"	Defoliated
2	"	"	—	Sept. 7	"		
3	"	June 21	—	July 15	—	"	S.p.i
1	"	"	—	"	—	"	M.p.i.
1	"	June 28	—	"	—	"	S.p.i
3	"	"	—	Sept. 7	M.p.i.		
1	"	July 8	—	"	S.p.i		
2	"	July 15	—	"	M.p.i.		
1	"	"	—	"	S.p.i.		
1	"	July 28	—	"	M.p.i.		
1	"	"	Trace	"	S.p.i.		
8 (checks)	"	Sept. 9	—				
1 (check)	April 21	"	—				
1	April 22	July 15	—	"	M.p.i.		
1	"	"	—	"	S.p.i.		
2	"	July 28	—	"	"		
7	April 25	June 16	—	"	"		
1	"	July 15	—	"	"		
1	"	"	Trace	"	"		
2	"	July 28	—	"	M.p.i.		
1	"	"	Trace	"	S.p.i.		
1	April 26	July 15	S.p.i.	"	"		
1	"	"	—	"	"		
1	"	July 28	Trace	"	"		
1	"	"	—	"	"		
3	April 27	June 16	—	"	"		
1	"	"	Trace	"	"		
1	May 2	July 28	—	"	"		
1	"	"	S.p.i.	"	"		
1	"	"	Trace	"	"		
1	May 3	"	S.p.i.	"	"		
2	"	"	Trace	"	"		
1	May 5	June 16	"	July 15	"	Sept. 7	S.p.i.
1	"	"	—	"	"	"	"
1	"	"	—	Sept. 7	"		
1	"	July 28	Trace	"	"		
1	May 7	July 8	—	July 15	—	"	Trace
1	"	July 15	—	Sept. 7	M.p.i.		
1	"	July 28	—	"	"		
1	"	"	Trace	"	S.p.i.		
2	May 12	June 16	S.p.i.	July 15	"		
1	"	"	"				
4	May 16	"	"				
4	May 19	"	"				
1	May 31	"	"				
1	"	July 15	"				
1	"	July 28	"				
2	June 4	Sept. 7	"				

(—) = disease not present; S.p.i. = severe petiole infection; M.p.i. = moderate petiole infection.

abnormal. The trees bloomed very early and three successive frosts destroyed the major portion of the crop. In the absence of much fruit, only twig growth with leaves could be bagged; but since both leaf and fruit infection occur at the same time and under the same conditions, the data obtained are applicable to fruit infection as well.

Petal fall for the Duchess orchard was recorded for April 6 and 7. The first bags were removed and new ones put on at intervals of two

or three days. The first bags were put on April 18, and, as the data show (Table 9) the disease was not present when these bags were removed at various intervals from May 23 to September 9, indicating that no infection occurred prior to April 18. Of a total of thirty-four bags put on during the period April 25 to May 7, twenty-one growths were disease-free, thirteen showed disease, three of which showed severe infection, and ten traces of infection. The primary infections, therefore, could not have been heavy. A study of the weather records shows that ideal conditions for infection occurred on April 26 and 27, about nineteen days after petal fall. The disease was apparent on Duchess fruit and foliage on May 19. The first heavy infections, however, occurred during the period May 9 to 12; a period five weeks after petal fall, marked by continuous damp, foggy weather, and precipitations amounting to 1.58 inches. As the season was abnormal no significance can be attached to the relation of the time elapsing between petal fall and infection (Fig. 11). The data (Table 9) further show that growth covered at intervals during the period May 12 to June 4 was severely diseased on examination later in the season.

Heavy infections occurred again in June. The data show (Table 9) that when bags were applied April 18, and removed at intervals from May 23 to June 10, no disease was present, and that when this same growth was examined on July 15 disease was universally present. A study of the weather after May 9 to 12 shows that infection could only have happened on June 19 to 21 during a precipitation of 3.7 inches, 2.99 inches of which fell on June 19 (Fig. 13). The fruit and foliage of many varieties some weeks after revealed a large increase in the disease even on mature apples. The infections for this period were even greater than those of May 9 to 11.

The month of July was dry with the exception of a precipitation of .68 of an inch on July 10. The month of August was characterized by heavy rainfall, amounting to 7.58 inches near Anna. Healthy growths exposed from June 28 and July 8, 15 and 28 for the rest of the season showed disease when examined on September 7. New lesions of the disease on the foliage and fruit were common in Illinois in September of 1921, the result of infections favored by the weather of August. The data do not reveal to what extent the conditions of July 10 were favorable for infection (it is probable that some infections occurred at this date at Anna). Heavy infections occurred in August, a significant fact in that the literature so far has always borne testimony against the probability of late infections.

Season of 1922 at Lilly and Other Points.—In this season the writer had opportunity to note the primary period of infection and the first appearance of the disease on several varieties in several sections of the state. The bagging experiment was conducted on Northwestern

Greening trees in the Lilly orchards (Table 10). The trees, however, were not generally diseased.

Petal fall for the Northwestern Greening occurred on May 5 and 6 and the first bags were put on May 17, eleven days after petal fall. The bags were removed at intervals from May 29 to July 20, and the growth was free of disease, indicating that no infection occurred on this variety at Lilly prior to May 17. Growth that was bagged on May 29 and June 1 and examined July 20 showed disease, indicating that primary infection occurred during the period May 17 to May 29. Heavy rains occurred at Lilly during the period May 23 to

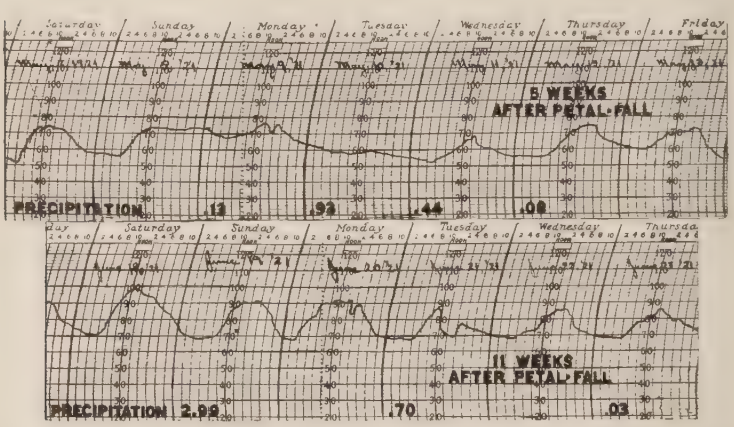

FIG. 13.—THERMOGRAPH AND PRECIPITATION RECORDS IN MILLER ORCHARD, ANNA, JUNE 18 TO 23, 1921

Time periods for Duchess variety; precipitation for twenty-four hour period, evening to evening.

26, approximately two and one-half weeks after petal fall. These dates for primary blotch infections are further supported by the fact that the first symptoms of the disease were apparent on June 7 to 8, or fifteen to sixteen days later. The period required for infection to become evident agrees closely with that of previous years for other varieties in Illinois. The month of June was relatively dry and unfavorable for infection. Of eighteen growths protected up to June 8, 16, and July 1, seven were diseased when examined again on July 20. This infection was associated with the heavy rains of July 1. Further infections occurred later in the summer. Of thirty-one growths bagged on May 17 and free of disease on July 20, fifteen showed symptoms of disease on October 15, indicating infection periods after July 26. Because of the small number of cankers on these trees,

the data are not as complete as would be expected from heavily infected trees. The experiment, however, gave valuable information regarding the time of primary infections and further demonstrated the fact brought out in previous years that heavy infections occur under ideal conditions as late as August.

Data on the dates of primary infection and the appearance of the first symptoms were also obtained from Anna, Olney, Urbana, Tonti, and Hillview. At Urbana, petal fall for the Duchess variety occurred on May 3, and for the Ben Davis and Northwestern Greening on May 5. Blotch first appeared on the fruit and leaves of the Duchess variety on June 4 and on the Northwestern Greening on June 6.

TABLE 10.—RESULTS OF BAGGING EXPERIMENTS ON NORTHWESTERN GREENING TREES, LILLY ORCHARDS, LILLY, 1922.

No. of bags	Date put on	Date taken off	Infection	Second examination		Third examination	
				Date	Infection	Date	Infection
1	May 17	May 29	−	Oct. 15	+		
1	"	"	−	July 20	−	Oct. 15	M.f. & p.i
1	"	"	−	"	−	"	S.f. & p.i
1	"	"	−	"	+		
1	"	"	−	"	−	"	
1	"	"	−	"	−		
1	"	June 8	−	"	−	"	+
1	"	"	−	Oct. 15	−		
1	"	"	−	July 20	−	"	S.f. & p.i.
1	"	"	−	"	−	"	Trace
1	"	June 16	−	"	−	"	M.p.i
1	"	"	−	"	+		
1	"	"	−	"	−	"	S.f. & p.i.
1	"	"	−	"	−		
1	"	"	−	"	M.p i.		
1	"	"	−	"	+		
2	"	July 1	−	"	−	"	−
1	"	"	−	"	−	"	S.p.i.
2	"	"	−	"	+		
1	"	"		Oct. 15	−		
2	"	"	−	July 20	+		
1	"	"	−	"	−	"	+
1	"	"	−	"	−		
1	"	July 10	−	Oct. 15	−		
1	"	"	−	July 20	−	"	S.p.i.
3	"	"	−	"	−	"	−
2	"	"	−	"	−	"	+
1	"	"	−	Oct. 15	−		
1	"	"	−	"	S.p.i.		
1	"	"	−	July 20	−	"	S.p.i.
5	"	July 20	−	Oct. 15	−		
1	"	"	−	"	Trace		
3	"	"	−	"	−		
8 (checks)	"	Oct. 15	−				
5	May 29	July 20	+				
1	"	"	M.p.i.				
1	"	"	−				
1	"	"	+	Oct. 15	+		
4	June 1	"	+				
1	"	"	−	"	−		
6	June 8	"	+				
1	"	"	M.p.i.				
1	"	Oct. 15	S.f. & p.i.				
1	June 16	July 20	−	"	S.f. & p.i.		
6	"	"	+				

(−) = disease not present; S.p.i. = severe petiole infection; M.p.i. = moderate petiole infection; S.f. & p.i. = severe fruit and petiole infection; (+) = disease present but degree not determined; M.f. & p.i. = moderate fruit and petiole infection.

It was first found on the Ben Davis, on June 8. The heaviest precipitation of the month of May occurred on May 25 and 26 (Fig. 14). The first infections of the season at Urbana also occurred at this time, or about three weeks after petal fall. Precipitations occurred frequently in the middle and early part of May, but since they were slight, conditions were unfavorable for infection; no precipitation occurred later in May.

The data from Anna are interesting and confirm the results of the previous seasons. The period of petal fall and of the calyx spray was April 17 to 20. Blotch was found on Yellow Transparent, Duchess, and Benoni for the first time in the period May 16 to 18, approximately four weeks after petal fall. Heavy rains occurred at Anna during the periods April 25 to 28 and May 2 and 3, and the conditions were ideal for infection, but the conditions in the latter period were responsible for the first infections as revealed by the

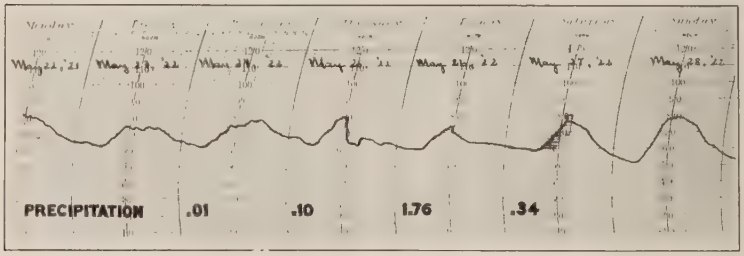

FIG. 14.—THERMOGRAPH AND PRECIPITATION RECORDS IN UNIVERSITY ORCHARD, URBANA, MAY 22 TO 28, 1922
Precipitation for twenty-four hour period, morning to morning.

results from several demonstration orchards for blotch control in Union county for the season of 1922. Eight orchards were selected and the spraying schedule called for applications at intervals of two, three, four, and six weeks after petal fall. This work was supervised by the assistant farm adviser in cooperation with the growers. In seven of these orchards the two-weeks spray was applied by May 2, but in the remaining orchard difficulty was encountered and the two-weeks spray was not applied until after the rainy period, with the result that the fruit and foliage of this orchard were heavily infected, while in the other seven orchards control was excellent. In the Miller orchard at Anna, the application of the two-weeks spray in the Benoni orchard was interfered with by rains of May 2 and 3, and the fruit from the trees which failed to get this application on time was diseased, while the fruit from trees sprayed before this period was clean. The data therefore indicate that the first infections occurred at Anna in the period May 2 and 3, or approximately two

weeks after petal fall. The disease was noted generally for the first time during May 16 to 18, or approximately two weeks after primary infection took place.

At Olney on Ben Davis, petal fall occurred April 18 and 19, and the disease was first found on May 21 and 22. Primary infection was traced to the heavy precipitation of May 3 and 4, about two weeks after petal fall. At Tonti, fifty miles west of Olney, the initial blotches on Ben Davis, Benoni, Grimes Golden, and Duchess fruit were found May 20 to 22. Petal fall for these varieties occurred on April 25 and 26. At Hillview, blotch was found on late varieties for the first time on May 24 and 25; petal fall was recorded for April 22 and 23.

The evidence obtained from three years of field work shows that primary blotch infections did not occur prior to two weeks after petal fall. It is certainly possible for primary infections to occur earlier in exceptional seasons, and no doubt a field study of the fungus over a period of years will bear out this statement. It is interesting to note that in southern Pennsylvania in 1922, according to Walton and Orton,[105] primary infection of the fruit occurred earlier than two weeks after petal fall. The results from this study also show that severe cases of fruit and leaf infection may occur in August under conditions existing in Illinois.

Conditions Associated with Natural Infection

The pycnidia do not swell and discharge their spores unless they are moistened. Study of the weather during the growing season has shown that heavy precipitation is required to bring about infection, since considerable wetting is necessary to soften the pycnidia sufficiently to lead to the expulsion of the spores, and to maintain moist conditions a sufficient length of time for spore germination. The pycnidia in the dead inner portions of the canker are the first to discharge spores, yet these may retain their spores until late in the summer notwithstanding the heavy rains earlier in the season.

Moisture alone is insignificant since the spores cannot germinate unless the temperature is favorable. Mature spores germinate early at the higher temperatures, that is, 25° C. (77° F.) and 30° C. (86° F.). The percentage of germination is ultimately as great at the lower temperatures, that is, 15° C. (59° F.) and 20° C. (68° F.) altho the rate of growth of the germ tubes is much less. It is safe to assume that if germination occurs normally at the low temperatures, infection may occur also at these temperatures as indicated by the conditions associated with primary infections. In the past three seasons, the primary infections have occurred during prolonged periods of moisture, accompanied and followed by low temperatures, and the summer infections in shorter periods of heavy rains and high temperature. Moist conditions during the night resulting from rains during the

day prolong the conditions favorable for spore germination and thus obviously for infection. There is ample evidence that light rains of short duration, even with warm temperature are not favorable to infection.

In 1920 at Anna the earliest infections occurred in the periods May 11 to 13 and May 16 to 18. The weather on May 11 was marked by continuous rains which were particularly heavy early in the afternoon. The maximum temperature of 22.8°C. (73°F.) occurred at 5 p. m., and rain continued thruout the night, and until 8 a. m. of May 12 (Fig. 12). May 12 was cloudy from 8 to 11 a. m., followed by hot sunshine, with thunder showers from 2 to 4 p. m. On May 13 the weather was cloudy and windy, the temperature was low, and rain fell again in the evening. For three days prior to May 11 the temperature was near 26.6°C. (80°F.) at midday, and the weather was fair and dry. Repeated examinations of the pycnidia during this period revealed that the spores were mature. The wet period of twenty-eight hours from noon May 11 to 4 p. m. May 12 was ideal for spore germination. Low temperatures prevailed during the period May 13 to 17, cloudy and windy weather from May 13 to 15, and heavy rains on May 16, 17, and 18. On May 19 and 21 the atmosphere was very humid, high temperatures prevailed at midday, and rains and thunder showers in the evenings. The precipitation for the period May 11 to 21 amounted to 6.13 inches. Prolonged wet weather of this kind is common in Illinois in the latter part of April and in May before the dry season begins.

The bagging results for 1920 on the Duchess variety at Anna show that further infection occurred in the period from May 30 to June 4 (Fig. 12). The weather for this period was as follows: thunder showers early in the morning of May 30, rain all day, amounting to .78 of an inch with intermittent periods of warm, bright sunshine, thunder showers at night and early in the morning of May 31, followed by clear weather and high temperatures for the day; cloudy on June 1 and 2, with high humidity; thunder showers in the evening of June 2 and rain all day on June 3, continuing until 11 p. m., and amounting to 1.54 inches; cloudy and high humidity on June 4. For one week prior to this period, and two weeks after, the weather was fair and dry.

The conditions associated with the first heavy infections in 1921 at Anna in the period May 9 to 12 were similar to those of the preceding year (Fig. 13). The precipitation during this period amounted to 1.58 inches, the days were cloudy and foggy, and the rains were prolonged and drizzly, interrupted by heavy showers. There was no sunshine during the entire period and the temperature was comparatively low. For almost two weeks prior to May 9 the weather was relatively dry and clear. After May 12, no rain occurred until May

27. Blotch was found on the fruit and foliage on May 28, as a result of the infection of this period, and was also found generally distributed in the county.

Extensive infections occurred on June 19, 1921, at Anna during heavy thunder showers from 7 a. m. to 3 p. m. (Fig. 13). The rain was forceful and amounted to 3 inches within the period of eight hours, thus drenching the orchard so thoroly that the leaves remained wet thruout the night. The temperature rose from 21.1°C. (70°F.) when the showers began, to 33.3°C. (92°F.) at 2 p. m., and remained above 21.1°C. (70°F.) for sixteen hours, that is, from 8 a. m. to 12 p. m. Both moisture and temperature, therefore, were favorable for rapid and early spore germination. The extensive infections of this period were evident about two weeks later. For many days preceding the thunder showers of May 19 the weather was clear, and for many days after it was dry, except for traces of rain on June 23, 24, and 25. The conditions of June 19 demonstrated the fact that with high temperature and heavy rain, infection occurs in a shorter time than in the spring when the temperature is low.

In the season of 1922 at Urbana heavy infections occurred during the wet period of May 25 and 26 (Fig. 14). The weather conditions during this period were as follows: continuous rains on May 25, amounting to 1.76 inches for the twenty-four hour period from 7 a. m. May 25 to 7 a. m. May 26, cloudy in the evening of May 25 and moist conditions thruout the night; cloudy weather on May 26 with occasional rains amounting to .34 of an inch. On both days there were thunder showers and the weather was continuously moist, while the temperature was never below 15.5° C. (60° F.). The heavy precipitation was ideal for infection, which was generally apparent on all susceptible varieties by June 9.

The rains and wet periods of the types described for May and June are responsible usually for the heaviest infections of the season. It is obvious, then, that sprays must be applied frequently in this season of the year. In the summer months the frequency of infection is less in the dry period which often extends thru the entire summer; consequently, spraying in this period for apple blotch is necessary only at wide intervals.

Development of the Fungus

Pycnidial Stage (a) *in the Bark.*—The twig growth of infected trees reveals in August, for the first time in the season, small purplish cankers, particularly noticeable at the nodes, and sometimes at the internodes. They are very common on the water sprouts.

Bark cankers are the result of two different modes of infection. First, they may result from the growth of the fungus from the diseased basal portion of the petiole across the abscise layer and into

the cortex of the twig. The majority of the node infections occur in this manner. Second, they may result directly from spore infections. The internode cankers are the results of such infections.

The pycnosclerotia appear rapidly with the enlargement of the canker, and their growth in size causes the rupture of the epidermis, and their exposure. Many, however, are not exposed until the following spring.

In Illinois the conditions in August and September are favorable for the growth of the fungus. These conditions prevail only for a short time, for usually in the latter part of September and early in October growth ceases, and the cankers remain nearly dormant thruout the winter. The inhibition of the fungus during the winter months is due to the prevailing low temperature and to the presence of an absciss layer of cells inside of the diseased region.

In March of the following year, the interior cells of the pycnosclerotium begin to differentiate and spores appear in the center. Spore formation continues until all of the pseudo-parenchyma context has become differentiated. First, a distinct sporogenous layer appears lining the small central cavity; this increases in size as the sporogenous layer progresses outward to the dense dothideaceous membrane. The conidiophores are of various lengths and frequently distinctly septate. The spores are produced acrogenously, each cell below the ejected spore giving rise to another spore. The pseudo-parenchyma context is gelatinous and in the process of spore formation some of the gelatinous substance is retained on the broad pole of the spore in the form of an appendage, but is dissolved with the maturity and germination of the spores (Fig. 9A1).

Early in April, the vegetative growth of the fungus in the canker is resumed and the cankers increase rapidly in size. The formation of new cankerous areas about the original canker continues actively thruout April and early May. With warm, dry weather, and with the formation of abscisss layers by the host, the progress of the fungus is inhibited again, and the cankers remain relatively quiescent during the summer months. Simultaneously with the enlargement of the canker, true pycnidia appear over the surface. There are present in the canker at the beginning of the season, therefore, two distinct sources of spores, first, the pycnosclerotia of the original canker, and second, the pycnidia formed with the advance of the canker.

With age the older portions of the canker become hard and dry, and rifting and exfoliation of the bark occurs. The canker becomes marked by definite growth areas and the tissues become dessicated and cracked. After the pycnidia have discharged their spores, the cankers become occupied by saprophytic fungi, notably of the genera Phoma and Septoria. Under the dead exfoliating bark, the periderm

layer, formed in advance of the fungus, develops to the extent of starving the fungus and repairing the wound.

In August and September the fungus grows rapidly, and simultaneously produces pycnosclerotia. New cankers now appear for the first time in the season and bear only pycnosclerotia. They appear to be the result of the same inocula which cause infection of the fruit and foliage, the incubation period being unusually long.

The fungus grows year after year in the bark, causes the increased annual enlargement of the cankers, and produces pycnidia in the spring and summer, and pycnosclerotia late in the summer. Growth,

TABLE 11.—ISOLATIONS OF *P. solitaria* FROM BRANCHES OF DUCHESS VARIETY TWO TO FIVE YEARS OLD

		Pure cultures, successful	Contaminated cultures, unsuccessful	Total number of cultures
Two-year wood	edge	3	4	7
Three-year wood	edge	3	2	5
	center	3	1	4
Four-year wood	edge	4	3	7
	center	4	1	5
Five-year wood	edge	5	2	7
	center	0	7	7

however, is much slower after the first year and the rate decreases with age. Previous investigators of apple blotch concede that the fungus is inhibited in its growth within three or four years and that the cankers disappear at the end of this period. This may be true for some varieties and under certain conditions, but it is not true generally for all varieties. The fungus may live indefinitely in the bark.

In order to establish proof of the longevity of the organism in the bark, isolations were made both from the advancing and the central portions of cankers from Duchess trees.

Table 11 shows the results of isolations from cankers on Duchess branches made February, 1921. The bark varied in age from two to five years. The unsuccessful cultures bore saprophytes. These saprophytes exist largely in the dead central portions of the cankers, but may also occur in the raised marginal living tissue of the canker. In March, 1921, isolations were again made from cankers on Duchess branches with the results presented in Table 12.

Later in March further isolations were made from edges and centers of cankers on twelve-year-old bark. Of nine isolations from the central areas, two gave pure cultures, and of thirteen isolations from the edge, six gave pure cultures.

These facts demonstrate that the fungus may continue its perennial habit in the bark for many years on this variety. Other varie-

ties very susceptible to bark infection likewise manifest the long-lived character of the fungus, i.e., the Benoni, Chenango, Northwestern Greening, and Missouri Pippin. Other less susceptible varieties like the Ben Davis, Yellow Transparent, and Rome Beauty, may support the fungus for only three or four years.

(b) *In the Fruit.*—The infections responsible for the initial blotches usually occur in May, ordinarily between two and three weeks after petal fall, tho they may occur even five weeks afterwards. In some years they may occur in the latter part of April, as in 1921.

TABLE 12.—ISOLATIONS OF *P. solitaria* FROM BRANCHES OF DUCHESS VARIETY FOUR TO EIGHT YEARS OLD

		Pure cultures, successful	Contaminated cultures, unsuccessful	Total number of cultures
Four-year wood	edge	3	3	6
	center	0	3	3
Five-year wood	edge	3	3	6
	center	3	3	6
Six-year wood	edge	3	3	6
	center	3	3	6
Seven-year wood	edge	2	4	6
	center	1	5	6
Eight-year wood	edge	4	2	6
	center	0	6	6

Symptoms appear two to three weeks after initial infection. The incubation period of the disease on the apple may vary according to climatic conditions and in some seasons may be shorter for early varieties, such as Duchess and Yellow Transparent, than for late varieties such as Ben Davis.

The pycnidia are usually present on the first appearance of the blotches, at first sparse and then many, but always definite and distinct. The pycnospores are produced rapidly and microscopic examination shows that they are present simultaneously with the appearance of the pycnidia. Usually within ten days after the first evidence of the lesions, the pycnidia are black and upon being crushed emit a mass of loose, distinct and apparently mature spores. The rapidity with which the pycnidia develop and form spores is remarkable. Oozing of spores from these pycnidia occurs in June and July, under favorable conditions leading to secondary infections of the fruit and foliage.

All of the pycnidia are not emptied under the first favorable conditions. The repeated infection of the new growth causes much increase in the disease on the fruit and foliage, which later serve as sources of further infections. The spores from the pycnidia on the primary blotches may reinfect the same apple. Examples of this are common in the summer. The new lesions are small and numerous and often appear directly below the large blotches.

The blotches increase in size with age. Late blotches resulting from late infections develop slowly and usually remain small. On early maturing varieties, such as the Duchess and Yellow Transparent, the blotches are small, while on the late maturing varieties, such as Ben Davis, Northwestern Greening, and Rome Beauty, they become quite large. As the blotches develop, the affected tissue becomes hard and dry, the growth of the underlying tissue is stunted, and the tension that arises from growth of the surrounding tissues results

FIG. 15.—SECTION THRU PYCNOSCLEROTIA FROM APPLE IN COLD STORAGE, FEBRUARY 10, 1920

in the cracking of the apple across the lesion. On the early maturing varieties the cracks are usually small, narrow, or absent, but on later maturing varieties they are quite large and deep. Pycnidia commonly form inside the cracks on the fleshy pulp.

The blotches increase in size and produce pycnidia as the apple develops. In August only pycnosclerotia are formed; the pycnidia formed previous to August also become pycnosclerotia by the rejuvenation of the sporogenous layer. Their walls become thick, carbonaceous, and the pycnosclerotia sometimes coalesce and become somewhat stromatic (Fig. 15). No pycnidia with spores, therefore, are present on the blotches after September. Early in the following spring the pseudo-parenchyma cells of the pycnosclerotia differentiate and by April or May many of the pycnosclerotia contain distinct and apparently mature pycnospores. Attempts to germinate the pycnospores obtained from these sources were generally unsuccessful.

(c) *In the Foliage.*—The disease is apparent two to three weeks after infection. Pycnidia with spores appear very early and can be recognized on the youngest lesions, maturing within a few days. In Illinois under favorable conditions these pycnospores are liberated in June, resulting in new infections of the fruit and leaves; these, then serve as additional sources of inoculum. After the spores are expelled, the pycnidia cease functioning. The lesions resulting from late infections both on the blades and petioles bear pycnosclerotia as on the fruit and pass the winter in this resting stage and usually produce pycnospores the following spring. Pycnosclerotia from overwintered foliage have been examined in the spring and frequently pycnospores have been found. Pycnosclerotia are more common on the petioles than on the blades, because the growth of the fungus on the petioles continues late in the season.

The development of the disease on the petioles offers a serious aspect. At first the petiole canker is small and ellipitical, and during the course of the season the fungus grows downward across the leaf scar into the cortex of the twig, usually girdling the petiole. As early as 1909 Scott and Rorer[79] were aware of the serious aspect of petiole infection. The significance of these petiole lesions was again emphasized by Gardner,[35] who thus explained the occurrence of so high a percentage of cankers at the nodes.

The initial lesions on the petioles commonly occur on the lower side. Growth is rapid at first and usually by August, particularly if infection occurs at the base of the petiole, the fungus has extended across the abscisss layer, and by the latter part of August or early in September the canker is evident, usually adjacent to the bud. Frequently the hyphae do not cross the abscisss layer until late in the season and the infection at the node is not evident until the following spring. The mycelium may grow downward within the petiole and across the abscisss layer before the leaf falls. Not all cankers about the nodes are the result of these basal petiole infections. The axil of the leaf furnishes a convenient place for lodging spores and water and thus for infection, resulting in frequent infection of the bud scales, and the direct infection of the bark of the twig around the bud. In Illinois 75 to 90 percent of the bark cankers are the result of node infections, resulting either from the direct infection of the bark, or indirectly by the vegetative growth of the fungus from the infected bud scales, buds, and petioles.

Serious petiole infection causes early leaf fall. In the season of 1921, in the general absence of a crop, no spraying was done for blotch, and petiole infection was severe. In southern Illinois, on the Duchess variety, girdling of the petioles was completed in late July

and early in August and the lower branches of the trees were conspicuously defoliated by the latter part of August.

Ascigerous Stage.—The morphology, development, and life history of *P. solitaria* and of the imperfect stage of *Guignardia bidwellii* show many interesting analogies.

In the development of black rot of grape, as reported by Reddick,[66] the pycnospores are produced in large numbers on the mummied berries from June until early August. They are discharged under favorable conditions and may produce new infections. In August, pycnosclerotia and spermogonia are produced on the new spots on the berries. Early in the spring some of these pycnosclerotia become perithecia, and others, true pycnidia. The simultaneous production of pycnosclerotia and spermogonia indicates the approach of the ascigerous stage.

In the development of *P. solitaria* on the leaves, only the late appearing lesions bear pycnosclerotia; the pycnidia which formed and functioned earlier in the season on early lesions terminate their existence after the pycnospores are discharged. On the fruit, pycnosclerotia are likewise present on late appearing blotches; but the pycnidia formed early in the season on blotches also become pycnosclerotia after spore discharge and pass the winter in this resting condition. All the fruiting bodies on the apple, therefore, pass the winter as pycnosclerotia (Fig. 15). A similar development has been reported for black rot on the grape berry by Prillieux,[61] Jaczewski,[49] Perraud,[60] and Prunet.[62] They report that pycnidia on the fruit pass into the resting stage in the autumn, and that the ascigerous stage may follow during the next spring. Quoting from Jaczewski:

"When grapes affected with black rot are dried or exposed to a low temperature (8° to 10° C.), the formation of stylospores ceases completely and the pycnidia fill up with a white compact pulp which consists of polygonal cells very rich in oil drops. The over-wintering, resting pycnidia, when exposed to the moist weather of the spring, differentiate again. In them, there develops a new activity of the pulp cells which leads to the formation of ascospores. The pycnidia therefore become, in this way, perithecia. It must be noted that all of the perithecia do not reach their full development and Prunet has already observed that the resting pycnidia (so-called sclerotia) in nature, transform more readily into pycnidia with stylospores than into perithecia."

The development is similar to *P. solitaria* on the fruit and, altho no ascigerous stage has yet been found, the indication is that its occurrence and formation is like that of the black rot fungus.

In the spring many of the pycnosclerotia of *P. solitaria* form pycnospores and many remain sterile. Attempts by the writer to

discover the ascigerous stage among overwintering fruit and leaves have been unsuccessful altho doubtless it may eventually be found as one of the final stages of the pycnosclerotium.

VARIETAL SUSCEPTIBILITY

The relative susceptibility of varieties of Malus Malus to apple blotch has been measured in the past largely by the severity and prevalence of the disease on the fruit. This method, however, does not measure the relative susceptibility of varieties nor the amount and severity of the disease on the bark since the bark shows a much wider variation to infection than the fruit. The comparative susceptibility of the bark is more significant also because the amount of infection on the fruit depends on the prevalence and distribution of the cankers on the tree. The Jonathan variety is a typical example, the bark of which is resistant under Illinois conditions. When this variety grows at a distance from infected Duchess or Ben Davis trees for example, spraying for blotch is unnecessary, but growing

TABLE 13.—RELATIVE SUSCEPTIBILITY OF APPLE FRUIT TO *Phyllosticta solitaria*

Very Susceptible		
Arkansas Black	Gilpin	Paradise Sweet
Arkansas Red	Harvest Pippin	Red Astrachan
Ben Davis	Hawthornden	Rhode Island Greening
Benoni	Huntsman Favorite	Rome Beauty
Bentley Sweet	Krauser	Royal Pearmain
Chenango	Lansingburg	Schockley
Clayton	Lawver	Smith Cider
Domine	Limbertwig	Sops of Wine
Duchess	Maiden Blush	Stark
Early Harvest	Mann	Tolman Sweet
Ewalt	Missouri Pippin	Wagener
Fameuse	Northwestern Greening	White Winter Pearmain
Gano	Oliver (Senator)	Yellow Transparent

Moderately Susceptible		
Aiken Red	Mammoth Black Twig	Rambo
Baldwin	May of Myers	Roman Stem
Bradford	McAfee	Salome
Champion	McIntosh	Shannon
Fink	Minkler	Willow Twig
Golden Russet	Northern Spy	Yellow Bellflower
Ingram	Ralls Gennett	Yellow Newton

Resistant or Slightly Susceptible			
Delicious	Jonathan	Stayman Winesap	York Imperial
Grimes Golden	Red June	Wealthy	Winesap

adjacent to such susceptible varieties the fruit of the Jonathan becomes infected.

The fruit of practically all the important commercial varieties of apples in Illinois is susceptible. Observations indicate that the Winesap variety as a whole is resistant, yet the fruit of this variety may be found infected under favorable conditions as is true of the fruit of many other varieties whose bark is resistant, such as, Sops of Wine, May of Myers (Rheinish May), Wealthy, Jonathan, Early Harvest, York Imperial, and Grimes Golden. Lewis[51] found under Kansas conditions that the Winesap and York Imperial are most resistant but that occasionally the fruit becomes infected.

In an orchard near Anna, several Benoni trees are partly top-worked with the Miller variety. In the absence of sprays, the apples on the trees become infected and there seems to be no wide difference in the susceptibility of these two varieties of apples. Only the Benoni

TABLE 14.—RELATIVE SUSCEPTIBILITY OF APPLE BARK TO *Phyllosticta solitaria*

Very Susceptible		
Benoni	Duchess	Missouri Pippin
Bentley Sweet	Fameuse	Northwestern Greening
Chenango	Lawver	Smith Cider
	Mann	
Moderately Susceptible		
Baldwin	Maiden Blush	Rhode Island Greening
Ben Davis	McIntosh	Rome Beauty
Gano	Oliver (Senator)	Stark
Limbertwig	Red Astrachan	Yellow Transparent
Resistant or Slightly Susceptible		
Aiken Red	Ingram	Red June
Champion	Jonathan	Sops of Wine
Delicious	Mammoth Black Twig	Stayman Winesap
Early Harvest	May of Myers	Wealthy
Fallawater	Minkler	Willow Twig
Fink	Northern Spy	Winesap
Grimes Golden	Ralls Genett	Yellow Newton
Huntsman	Rambo	York Imperial
Susceptible to Bark Infection but Degree of Susceptibility Doubtful		
Arkansas Black	Golden Russet	Salome
Arkansas Red	Harvest Pippin	Schockley
Bradford	Hawthornden	Shannon
Clayton	Lansingburg	Tolman Sweet
Domine	McAfee	Wagener
Gilpin	Roman Stem	White Winter Pearmain
	Royal Pearmain	

twigs and branches, however, were cankered. The fruit of the Miller trees located at a distance from Benoni trees was always free of blotch even when unsprayed. Similarly Adams[1] in Pennsylvania reports an instance where Smith Cider was extremely susceptible to canker infection while Grimes Golden growing adjacent was but slightly infected and on the York Imperial it was impossible to find cankers. The fruit of the last two varieties, however, was badly infected. These and other observations warrant the statement that the infection of the fruit of any variety is directly associated with its proximity to infected bark. It seems then that in selecting varieties for the orchard, the susceptibility of the bark rather than of the fruit is worthy of most consideration. Planting of susceptible varieties of high commercial value may be recommended, but their location in relation to bark resistant varieties should be planned carefully.

A limited number of varieties in Illinois are seriously susceptible to bark infections. About an equal number are moderately so, while the majority are resistant or only slightly susceptible. The Duchess, Smith Cider, Northwestern Greening, and Missouri Pippin are examples of varieties whose fruit and bark are extremely susceptible. The fruit of the Yellow Transparent is very susceptible but to a less degree than the fruit of the Smith Cider and Ben Davis. The bark of the Ben Davis is more susceptible than the bark of the Yellow Transparent and frequently the latter is quite resistant. The fruit of the Rome Beauty is very susceptible, but according to the susceptibility of the bark this variety is in the class with the Ben Davis. The Jonathan, Grimes Golden, and York Imperial varieties might be classified alike because of the resistance of the bark and because the fruit is less than moderately susceptible. The variations in the susceptibility of the fruit and bark in different localities prevent satisfactory separation of varieties into more than three classes of susceptibility. (Tables 13 and 14.)

DISSEMINATION

When bark-resistant and bark-susceptible varieties are growing in adjacent rows the fruit of the bark-resistant varieties becomes infected usually only on the side exposed to the infected trees and within the drip of the infected branches. This indicates that the dissemination of spores is limited to a comparatively short distance during periods when conditions are favorable for infection. The constant proximity of the fruit and foliage lesions to the cankers on the same tree also indicates that the infectious material is carried only a relatively short distance under these conditions. The washing rains associated with infection carry the spores downward to the lower half

of the tree as is always evidenced by the relative absence of the disease high up on the tree and the abundance of it on the lower branches. The splashing rains and washings assisted by wind carry the fungus into the adjacent rows.

In Knox county, in September, 1921, the disease was found confined to a few trees in a block of Northwestern Greening and the examination of the twigs showed that a few isolated cankers were present on the preceding season's growth. A similar instance was found in the same season at Mount Morris, Ogle county, on a single tree in the center of a block of twenty-year-old Northwestern Greening. A thoro examination of the orchard revealed a single canker. Both of the above orchards are located in counties where serious isolated cases of the disease are known.

The spores, which are extruded in gelatinous masses, may retain their vitality for some time and dried fragments of the exudate and individual spores may be carried by wind currents for some distance. Ordinarily, pycnospores are short-lived, but in the case of *Phoma uvicola*, a very closely related organism, according to Scribner[80] the pycnospores may germinate after six months under dry conditions. According to Rathay[65] the dissemination of the pycnospores of the black-rot fungus is effected by water and wind, the former freeing the binding substance of the cirrhi. Viala, according to Rathay[65] (p. 311), observed that on continued drying the slimy cirrhi shrivel and crumble away and that the wind blows away small fragments holding three to four pycnospores. The dissemination of the spores of *P. solitaria* under dry conditions by the wind, as the above authors report for black rot, may account for out-croppings of apple blotch in healthy orchards at some distance from disease centers.

Man is the most important agent of dissemination. Apple blotch is frequently found in Illinois on young apple trees in shipments from nurseries in the blotch infested area of the United States. Adams[1] has noted several instances of its presence in Pennsylvania on nursery stock from the Middle West.

The great danger of infesting the nurseries lies in the nurseryman's use of infected American-grown apple-seedling stock. The great bulk of the apple seedlings come from the region between Rossville and Perry in the Kaw valley of Kansas. Apple blotch has been prevalent in Kansas since 1903. Conclusions have been reached to the effect that American-grown apple seedlings, especially those grown in localities where apple blotch is prevalent, are an important means of distributing the disease, especially when the practice of budding is followed. There is sufficient evidence that the disease is frequently present on seedlings coming into the eastern states from sections west of the Mississippi river.

In Illinois only a relatively small percentage of the seedlings are budded; the majority are grafted. In both cases, however, even tho the stock is healthy, the danger of making diseased trees is obvious since 80 to 90 percent of the infection appears at the buds, which sometimes is not evident until the spring following infection. Since the disease is so prevalent on susceptible varieties in the east and south-central regions of the United States, the chances of selecting disease-free buds here is not very great and if the seedlings are grafted, the probabilities of selecting disease-free scions is less. There is no danger of disseminating the disease on seedling stock provided it is used only for grafting purposes, topping back to the root is practiced, and healthy scions are employed.

CONTROL MEASURES

HISTORICAL: METHODS THAT HAVE BEEN ADVOCATED

In the earliest experiments on the control of apple blotch, conducted by Crandall,[23] Scott and Quaintance,[77] and Scott and Rorer,[78] measures were recommended which at that time gave satisfactory control of the disease. Crandall[23, 24] found that apple blotch yielded quite readily to applications of liquid Bordeaux. In 1907 Scott and Quaintance[77] reported that the periods of infection were about the same for blotch as for bitter rot and recommended the same treatment for both diseases; namely, four applications of Bordeaux at intervals of two weeks, beginning six weeks after petal fall. This schedule was modified later by Scott and Rorer[78] under the belief that the principal infections occurred from four to six weeks after the petals had fallen. Consequently, they recommended four applications of Bordeaux, beginning three to four weeks after petal fall, again four weeks later, and the third and fourth applications at intervals of three weeks thereafter. The second and succeeding applications corresponded with the treatment for bitter rot, so that one course of treatment controlled both diseases. Hewitt[46, 47] recommended practically the same schedule for blotch and bitter rot in Arkansas. The idea of applying a spray three weeks after petal fall for blotch originated with Dickens and Headlee[25] of Kansas. The most satisfactory results were obtained with three applications of Bordeaux applied at petal fall and again at three and ten weeks later. Lewis,[51] in 1913, confirmed these results and recommended an identical spraying schedule.

Many of the earlier investigations on apple blotch control have been concerned with the study of the relative merits of Bordeaux and lime sulfur. In 1913 Lewis[51] reported that lime sulfur was less effective than Bordeaux for blotch control, and that by the continued

use of Bordeaux during successive seasons the disease could be almost completely eradicated from the orchard. These results coincided with those of Scott[75, 76] in Virginia in 1910. The results of Blair et al[8] like those of Scott, and Lewis, showed a greater efficiency from the use of Bordeaux. The treatment which seemed to be of most value, however, when russet and foliage injury are considered, involved the use of lime sulfur for the early applications and Bordeaux for the later applications. On the basis of their results, it seemed that applications at intervals of ten days after petal fall, two to three weeks later, and ten weeks after petal fall were worthy of recommendation in Illinois, using lime sulfur for the first two applications and Bordeaux for the ten-weeks spray. In 1915 Gunderson[42] recommended the substitution of lime sulfur for Bordeaux for the early applications in order to avoid injuries to the fruit and foliage. He recommended applications at three weeks after petal fall and at sufficient frequency thereafter until July 1 to keep the fruit coated. In 1916 Gunderson[43] considered Bordeaux superior to lime sulfur for blotch and stated that applications at intervals of three, five, and seven weeks after petal fall were the important sprays. Walton[104] offered the same recommendations for Ohio, with the exception that where the disease is light or there is danger of injury from Bordeaux, lime sulfur should be used. The results of the spraying experiments of Gunderson[44] in 1917 and 1918 showed that the lime sulfur and Bordeaux sprays were equally effective and that the three- and five-weeks sprays were the most important.

In 1918 Brock[10] employed a schedule consisting of applications three, five, seven, and nine weeks following the bloom, and reported inconclusive and disappointing results, stating that it was impossible to bring blotch under satisfactory control in a neglected, susceptible orchard in one or two years. Brock believed that very susceptible varieties should receive applications of lime sulfur or Bordeaux at intervals of three, four, five, and six weeks after the bloom. He[12] considered the six-weeks application generally unnecessary and consequently recommended the three-, four-, and five-weeks applications under the belief that no infections occur later than five weeks after petal fall.

The results of Gunderson[45] for the three-year period 1916 to 1918 showed that applications three weeks and five weeks after petal fall, with additional sprays under conditions of heavy rains, successfully controlled apple blotch and that the results from Bordeaux and lime sulfur were practically equal.

In Nebraska, Cooper,[20] working on the assumption that the primary and greatest infections occur during the four- to five-weeks period after petal fall, recommended a schedule involving applications of Bordeaux

three weeks after petal fall, again when spraying for the second-brood codling moth, and an additional intermediate spray five weeks after petal fall for heavily infected orchards. Cooper's results also claimed the superiority of Bordeaux over the lime sulfur.

In Oklahoma,[55] on the basis of five years' work, the Experiment Station reports the worthlessness of the lime sulfur spray for apple blotch control. For effective control, applications of Bordeaux mixture are recommended at intervals of 2, 4, 5, and 7 weeks after the petals fall.

Ballou and Lewis[4] of Ohio, on the basis of one season's work, obtained excellent control of blotch with Bordeaux sprays following a 2, 4, 10 weeks schedule. The same schedule with lime sulfur was much less effective but produced the only really smooth, bright, and attractive apples. It is interesting to note, however, that where the 2, 4, 6, 10 weeks schedule with lime sulfur was followed, the results were as good as with the Bordeaux sprays.

With the introduction of dusts as substitutes for sprays attempts were made to control apple blotch with dusts. The first experiments by Crandall[23, 24] with Bordeaux dust demonstrated that the dust was inefficient in controlling the dominant apple fungi among which *P. solitaria* was included; a conclusion which was likewise reached by Fromme[a] et al[34] from two years' experiments with Bordeaux dusts in Virginia, contrary to the earlier report of Fromme and Ralston[33] that control with Bordeaux dust was as striking as it was unexpected. In 1918 Brock[11] reported the failure of sulfur dusts to control apple blotch in Illinois, and Giddings,[38] experimenting with various types of dusts, stated that dusts could not be recommended in West Virginia for the control of apple blotch or any of the dominant apple fungi.

A new era appeared in the history of apple blotch control when the spraying results of Rolfs[72] in Oklahoma, Brock[14] in Illinois, Stover et al[54, 90] and Beach[5-7] in Ohio, emphasized the need of applying a spray somewhat earlier than the three-weeks application. On the basis of their results, the two-weeks spray has been recommended in many states as the first spray in the schedule for the control of this disease. In Illinois, Brock[14] observed that better control was possible with the application of the two-weeks spray of either lime sulfur or Bordeaux. The results convinced him that blotch infections must occur in many seasons prior to three weeks after petal fall. Beach's results from the two-, four-, six-, and ten-weeks spray schedule with hydrated lime-Bordeaux demonstrated the possibility of obtaining perfect control of apple blotch in Ohio under the most severe cases of infection. We are indebted to Rolfs,[72] however, for first

[a]Information obtained from personal correspondence.

emphasizing the necessity of an application at two weeks after petal fall. He states, "The spring of 1918 was unusually wet and we failed to get our second spray on the trees until about the middle of the third week. Consequently fully 50 percent of the apples became infected with the blotch organism (*Phyllosticta solitarium*). The results . . . show that the second spray if applied in three weeks is not soon enough to prevent the early blotch infections . . ." This has also only recently been found to be true for Pennsylvania conditions.[59]

Supplementary to the use of fungicides for the control of apple blotch many investigators have stressed pruning of the cankered branches, for it has been known from the earliest investigations that the cankers serve as the annual sources of inocula. Others have recommended a general thinning-out pruning before the spraying season begins in order to facilitate more thoro and general distribution of the sprays.

Beach,[5] in 1922, suggested fertilization of weak and badly diseased trees with nitrate of soda or sulfate of ammonia to induce an abundance of new growth which could be kept free from cankers by spraying and which would gradually build up a healthy fruit spur system.

Dormant Spraying

As early as 1910 apple growers in some sections of southern Illinois observed that dormant applications of lime sulfur or copper sulfate were of some value in reducing the amount of apple blotch on the fruit. No experiments, however, had been undertaken to determine this point. Watkins[106, 107] as early as 1912 stated from field observations that the difference in the amount of infection on trees receiving and not receiving the winter lime-sulfur application was not sufficient to attract attention and yet, without the confirmation of any experiments, he felt that winter applications of lime sulfur should reduce the amount of infection by permitting less potential inocula. Watkins strongly urged upon the growers the necessity of this spray primarily for scale, but his great confidence in it as a bark spray, and his desire to see growers acquire the practice of dormant spraying, led him to recommend it as well for superficial bark diseases like bitter rot and blotch. Wallace,[103] experimenting on this phase of blotch control in Indiana, claimed remarkable results with an application of strong lime sulfur and stated, "It seems probable that this disease which costs Indiana growers as much as any other apple disease will eventually be controlled by winter spraying." The assumption was also made that there would be fewer fungus spores left to start infections. Later, Douglass[27-29] claimed that one dormant application of a very strong lime-sulfur solution "would

eat its way into the shallow canker and kill the fungus in its stronghold." Gunderson's[44, 45] results show that dormant applications of copper sulfate, lime sulfur, or Scalecide have no effect upon the growth of the cankers or upon pycnidial formation and "altho no examinations were made for spores, it is reasonable to conclude that these were produced." Brock,[14] from the results of several experiments, and Oskamp[58] have also reported no apparent blotch control from dormant sprays.

The failure to recognize the merits of certain dormant sprays for blotch control has resulted from the fact that investigators have measured the effect of these sprays entirely by the amount of blotched fruit. Their effort was directed primarily to the extermination of the organism from the living tissues by external applications of toxic substances, not realizing the close association between fungus and host, and the existence of the fungus in the raised margins of the cankers securely protected from the influence of any chemical. None of these investigators used the microscope in the field to determine the actual condition of the spores after the applications.

In the absence of such microscopic evidence they were at a loss to explain their negative results. The fact that there was no apparent difference in the percentage of control on trees receiving only the regular summer sprays and trees receiving the dormant spray in addition is obvious. Indeed, in some seasons during these years, growers occasionally observed a marked difference in infection on trees receiving and not receiving the dormant spray, and their results led them to continue the practice of late dormant spraying. The diversity of results among growers and investigators was due to the varied conditions of spraying, that is, the kind of spray, the time and frequency of the applications, the thoroness of the applications, and the amount of infection, and to other factors inherent in the habit of the cankers.

The Department of Botany of the Purdue Agricultural Experiment Station[63, 64] found from laboratory tests that a strong lime-sulfur solution killed the spores of the fungus in exposed pycnidia and not the mycelium in the tissues of the bark, but their field "results of 1919 indicated that the dormant spray does not in any way diminish blotch infection on the fruit and foliage." The writer[40, 41] claimed that for reasons connected with the habit and life history of the fungus it is possible to destroy a percentage of the season's infections with late, strong applications of copper sulfate or lime sulfur, but that the extermination of the fungus by spraying is impossible. This report also stated that the summer sprays were absolutely necessary to control the disease. In confirmation of this report, Brock[16] recently has stated, "Heavy applications of lime sulfur at winter strength applied at the delayed dormant stage are partially effective in reducing the

percentage of infection, altho their use alone would not be considered as approaching control."

EXPERIMENTS WITH DORMANT SPRAYS

As has been mentioned previously, the cankers remain relatively dormant during the winter months, altho their increase in size and the formation of pycnosclerotia occur during this period under warm, moist conditions. In the spring after the buds swell and open, a rapid enlargement of the canker is effected and true pycnidia are formed whose spores play an important part in the season's infections.

Previously it has been stated that differentiation of the pycnosclerotia begins in March and that distinct spores are present in March and April. The pycnosclerotia may become exposed at the time of their formation in autumn, in winter, or in the following spring. Obviously the nearer the development of the pycnosclerotia approaches the period of blossoming and initial infection, the greater is the number

TABLE 15.—APPROXIMATE NUMBER OF EXPOSED AND UNEXPOSED PYCNOSCLEROTIA ON CANKERS EXAMINED AT INTERVALS DURING SPRING OF 1923 AT URBANA

Number of cankers examined	Date of examination	Number of pycnosclerotia	Number exposed	Number unexposed	Percentage exposed
21	February 7..	1039	245	794	23.6
26	March 23....	1017	491	526	48.3

of exposed pycnosclerotia. In other words, before the dormant season for the host terminates some of the pycnosclerotia are covered, some exposed, and no matter how late the strong dormant spray is applied not every pycnosclerotium can be touched. It is common to find pycnosclerotia on the outer, purplish areas of the older cankers covered even late in the dormant season, because the thickness and strength of the bark prevents their exposure. One-year wood and, particularly, water sprouts show many exposed pycnosclerotia before the winter begins. Table 15 shows the relative number of exposed and covered pycnosclerotia on cankers in February and March, 1923.

In order, therefore, to get the greatest advantage from dormant sprays for blotch control, it is necessary to delay the application as late as the trees will tolerate it without injury. Growers frequently apply the dormant spray when the buds are beginning to show pink color. This late application would be very desirable since most of the pycnosclerotia are then exposed, were it not for the fact that the trees cannot then be drenched without causing some injury. Therefore, the application should be made a little earlier when the buds are swelling and are green, even tho not as many prospective infections are likely thus to be suppressed.

TABLE 16.—DIFFERENCE IN THE NUMBER OF APPLE BLOTCH INFECTIONS ON DUCHESS APPLES AS THE RESULT OF DORMANT SPRAYS AT ANNA, JUNE, 1920

Dormant treatment	Number of apples examined	Total number of infections
Scalecide	15	327
Lime sulfur (1-8)	15	217
Scalecide	15	257
Lime sulfur (1-4)	15	120
Scalecide	15	275
Lime sulfur (1-8)	15	213

Another factor which deserves emphasis is the need of thoroness in the applications. Every exposed pycnosclerotium must be covered by the fungicide if it is hoped to kill the spores within. Slipshod methods of spraying, applications from one side of the trees, and incomplete covering of the trees have been in part responsible for the contradictory results. Every portion of the bark must be covered.

FIG. 16.—SPORES OF *P. solitaria* FROM PYCNOSCLEROTIA FROM CANKERS SPRAYED WITH COMMERCIAL LIME SULFUR 32° BAUMÉ, 1-8, LATE DORMANT SEASON

The nature and strength of the spray is of fundamental importance. Late in March, 1920, at Anna, Duchess and Benoni trees were sprayed with commercial lime sulfur (32° Baumé, 1-4½) and others with copper sulfate (1-4½). Both sprays were effective in killing the spores. In a neighboring orchard Duchess trees were sprayed with commercial lime sulfur (32° Baumé, 1-8) on March 29 and 30 with the same results. Scalecide applied at the same time and at the rate of 4 gallons of Scalecide to 50 gallons of water had no apparent effect upon the spores. In tallying the amount of infection on the trees receiving and not receiving the effective dormant sprays no difference was apparent in the amount of infected fruit, altho counts of the number of infections on apples from trees sprayed with Scalecide and from trees sprayed with lime sulfur, showed that there was a difference in the number of infections, and that the difference was greater on the apples from trees which received the double strength of lime sulfur, as is shown in Table 16.

Since Scalecide had no toxic effect on the spores the trees receiving only this spray may be regarded as unsprayed so far as blotch infection is concerned. The apples from which the data in Table 16 were obtained were picked at random from the trees and the picking was done blindfolded. The percentage and number of seriously and slightly infected apples from these pickings are found in Table 17.

TABLE 17.—NUMBER AND PERCENTAGE OF INFECTED DUCHESS APPLES FROM TREES SPRAYED WITH SCALECIDE AND WITH LIME SULFUR

Dormant treatment	Number of apples examined	Apples seriously infected		Apples slightly infected	
		Number	Percentage	Number	Percentage
Scalecide	45	37	82	8	18
Lime sulfur	45	29	64	16	36

In these tables "slightly infected" is interpreted to mean less than six infections per apple, "seriously infected," more than five infections. Commonly, the seriously infected fruit bore as many as fifty or more infections. Of forty-five apples examined from the trees receiving Scalecide, twenty apples showed more than twenty infections, eight of which showed more than forty infections; while of

TABLE 18.—EFFECT OF DORMANT SPRAY UPON AMOUNT OF APPLE BLOTCH ON DUCHESS APPLES (after W. S. Brock[16])

Treatment	Percentage affected			
	Serious	Slight	Total	Free
Double strength lime sulfur	35.2	48.5	83.7	16.3
No dormant	76.7	2.2	78.9	21.1

forty-five apples examined from the trees receiving lime sulfur, twelve showed more than twenty blotches of which only three showed more than forty blotches. Brock[16] recently has reported some control of apple blotch with dormant lime sulfur (Table 18). The real differences in the number of infections appear in the percentage of slightly and seriously infected fruit.

On March 22, 1921, at Anna, three Benoni trees were given a heavy application of homemade lime sulfur (31° Baumé, 1-3½). At the time of the application, the fruit buds were showing pink color and the young leaves were well exposed. The spraying was done under windy conditions and altho drenching was resorted to, microscopic examination of the spores on March 31, and later in the season, showed that generally they were not killed, even in cankers which were specifically marked and heavily covered with the spray. This led the writer to lose confidence in homemade lime sulfur for dormant spraying of apple blotch control. In another portion of the same orchard, Duchess, Ben Davis, and Rome Beauty trees were sprayed late with the lime sulfur (com. 33° Baumé, 1-8) and examinations of the

pycnidia from these trees on April 10, 1921, revealed the dead collapsed condition of the spores, altho several pycnidia were found full of apparently normal spores. Other blocks of Duchess trees in the orchard were sprayed in December, and again in March with lime sulfur (com. 32° Baumé, 1-8) and no pycnidia could be found with normal spores on March 22, 1921. However, since the fungus was not killed, the cankers enlarged in April and a new source of infection arose. Nevertheless, the fruit on these trees was relatively

TABLE 19.—RESULTS FROM TREATMENT OF CANKERS WITH CHEMICALS LATE IN THE DORMANT SEASON, URBANA, 1922

Treatment	First application		Second application		Result[1]
	Strength	Date	Strength	Date	
Phenolene	1½–50	April 3	1 qt.–15 gals.	April 15	−
Scalecide	4–50	April 3	3½–50	April 13	−
Spra-Mulsion	6–50	April 3	3½–50	April 13	−
Dry lime sulfur	20–50	April 3	13–50	April 13	−
Copper sulfate	1–5	April 13	(Not duplicated)		+

[1] (−) indicates that the spores were not affected; (+) indicates that the spores were affected.

free of blotch when the orchard was examined on May 27, while in a neighboring Duchess orchard where the dormant spraying was only partially effective in killing the spores, and where the trees were much less severely cankered, the apples were quite heavily infected. Similar results have often been observed by growers.

In the spring of 1922, dormant spraying experiments were undertaken on Northwestern Greening trees in the University Orchards at Urbana. The materials used were Phenolene, Scalecide, Spra-Mulsion, copper sulfate, and dry lime sulfur. Two dormant applications were made with each solution excepting with copper sulfate, as noted in Table 19.[a]

On April 23 and June 5, cankers from the trees receiving these applications were brought into the laboratory and it was found that the pycnidia and spores from the trees receiving the strong copper-sulfate spray were dead. All other sprays applied had no effect upon the fungus. No data were taken upon the relation of these dormant sprays to the amount of infection upon the fruit, since the trees were adjacent to one another in the same row. In a near-by orchard a heavily cankered tree was sprayed on April 3 with copper sulfate in the proportion of 1 pound of copper sulfate to 15 gallons of water and the examination of the pycnidia later in the season showed the toxic effect of the fungicide.

The evidence obtained from these experiments with dormant sprays indicates that it is possible to reduce the amount of the season's infec-

[a] The Phenolene, Spra-Mulsion, and dry lime sulfur were furnished by the Sherwin-Williams Company; the Scalecide by the Pratt Fungicide and Insecticide Company.

tion by dormant spraying with commercial lime sulfur or copper sulfate. It seems from these results that a dilution of commercial lime sulfur (32° Baumé, 1-8) recommended for San José scale in Illinois orchards is strong enough to kill the spores in the exposed pycnidia. The experiments also show that copper sulfate (1-4½ and 1-15) produces the same effect. Until more definite evidence is secured a solution of copper sulfate prepared in the proportion 1-10 can be applied with the assurance of success, since the greater the concentration, the greater the deposit, and the less rapidly the material is likely to wash from the branches or become too diluted before accomplishing its effect. The practice of applying two dormant sprays for bark-susceptible varieties of apples has been followed by some southern Illinois orchardists and is a sound one. For the purpose of suppressing as much prospective infection as possible, it is particularly desirable to spray as late as possible. The spring applications are also more effective than the autumn applications for the control of San José scale. It is suggested that the entire orchard be sprayed with commercial lime sulfur (32° or 33° Baumé, 1-8) primarily for scale, and the blotch-cankered varieties again very late with copper sulfate (1-10). With the present cheap price of copper sulfate and the value that can be derived from this spray, southern Illinois growers can well afford its application. If the duplicate application is not possible, then the application of commercial lime sulfur only (32° or 33° Baumé, 1-8) for the bark-susceptible varieties should be postponed as late as the trees will tolerate it.

The writer claims that the dormant spray reduces the season's infections, but since the remaining infection that does not come within the reach of the dormant spray may be large, the difference between the amount of disease on the fruit of those trees receiving and those not receiving the application may not be sufficient to attract attention.

Effect of the Fungicide

The difference in the appearance of the spores affected by chemicals and the normal spores is very striking. In contrast to the normal turgid, broadly elliptical spores containing large globules (Fig. 9A), the affected spores are collapsed, like irregularly shaped rods or clubs, usually retaining the attached collapsed appendage (Fig. 16). The original globules in the spore cell are united into an irregular, homogeneous mass and their individuality lost. The pycnidia affected by the fungicide are brittle, rigid, and inflexible, and the dead spores can be pressed from them only with difficulty. In the summer, the contents of these pycnidia are dry and collapsed into a hard mass and the individual spores lose their identity (Figs. 17, 18).

The pycnidia are conspicuously larger after rains than during dry periods, due to the swelling of the concentrated food materials in the gelatinous matrix. When cankers are covered with lime sulfur or copper sulfate it is evident that these chemicals in solution over the

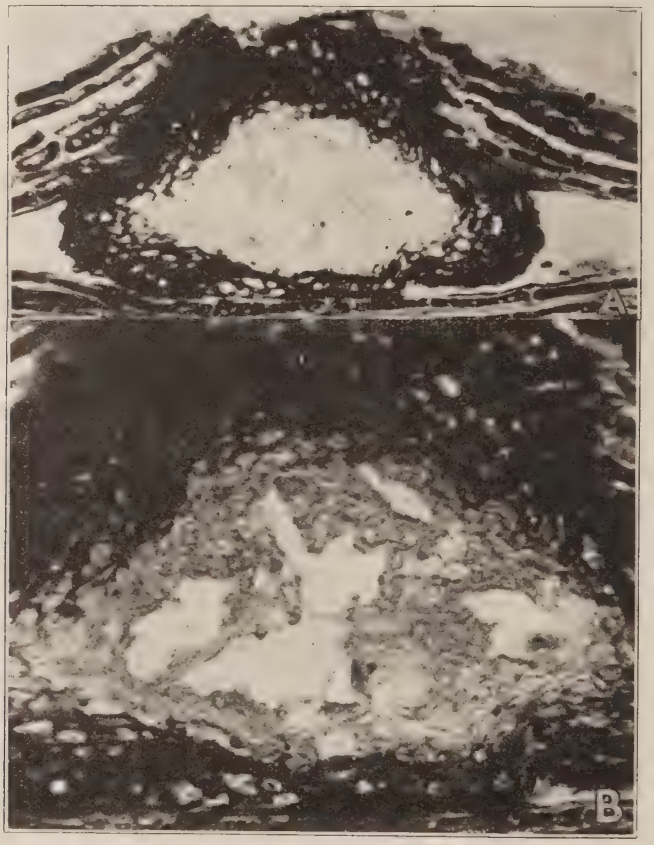

FIG. 17.—SECTIONS THRU PYCNOSCLEROTIA, SHOWING THE EFFECT OF DORMANT SPRAY

(A) Collected June 7, 1920, from canker sprayed with copper sulfate; (B) higher magnification of A, showing the dead, irregular content of the pycnosclerotium.

cankers are carried into the matrix of the exposed pycnosclerotia. Therefore, during wet periods, the effect of these substances may be expected to be at the maximum. Cooper[21] found that the stromata of *Nummularia discreta* absorbed copper sulfate and lime sulfur readily

in solution, with the result that the quantities of spores expelled and the percentage of germinations were considerably reduced. The greatest effect was obtained with copper sulfate. He suggested spraying the cankers with copper sulfate at the rate of 1 pound to 2 gallons of water as one means of preventing the dissemination of ascospores in the spring. For use on apple blotch cankers the copper sulfate seems to be more desirable than lime sulfur. The fact that it is

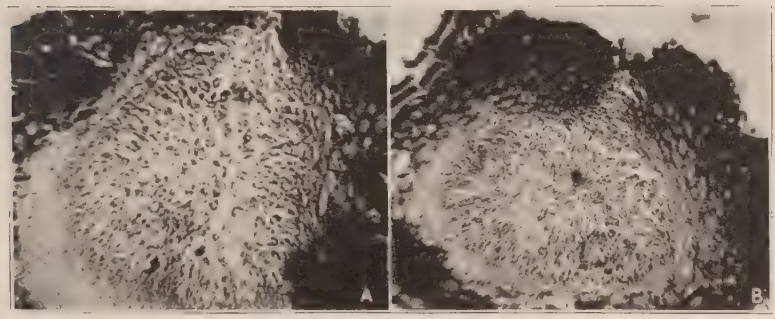

FIG. 18.—SECTIONS THRU PYCNOSCLEROTIA

(A) From canker receiving dormant spray, collected April 18, 1920; (B) from an unsprayed canker, collected March 21, 1920.

readily soluble, and that the solution readily passes into the fungus and the dead tissues of the canker, and that it persists in these portions long after the application, gives it an added advantage.

To illustrate the need of moisture to produce the maximum effect with the fungicides, the following observations are noteworthy. On March 30, 1920, at Anna, Duchess trees were sprayed with commercial lime sulfur (32° Baumé, 1-4½). On the night of March 31 there was a heavy rain and the following morning pycnidia from these trees were examined and the contents found to be dead. Four young Duchess trees in another orchard at Anna were drenched with copper sulfate (1-4½) and on the following day most of the spores appeared normal, no precipitation occurring between the time of application and the observation. A few days later a heavy rain fell and when the spores were examined on April 8 after the rain they were dead (Plate 4). It seems then, that the spray alone is not sufficient to carry the chemicals into the pycnidium and that a wetting is necessary to soak and soften the carbonaceous membrane.

EXPERIMENTS WITH SUMMER SPRAYS

The plan of the spraying experiments has been based largely on the life history of the fungus. The results of the treatments con-

TABLE 20.—PLAN OF APPLE BLOTCH CONTROL EXPERIMENT, ANDERSON DUCHESS ORCHARD, ANNA, 1920

Plat No.	Treatment	Applications						
		Calyx	2 wks.	3 wks.	4 wks.	5 wks.	6 wks.	7 wks.
1	Lime sulfur	×	×	×	×	×	×	..
	Bordeaux	..	..	..	..	..	..	×
2	Bordeaux	×	×	×	×	×	×	×
3	Check	..	..	..	..	..	..	..
4	Bordeaux	..	×	×	×	..	×	..
	Lime sulfur	×	..	..	..	..	..	..
5	Lime sulfur	×	×	×	×	..	×	..
6	Bordeaux	..	..	×	×	×	×	×
	Lime sulfur	×	..	..	..	..	..	..
7	Bordeaux	..	×	..	×	×	×	×
	Lime sulfur	×	..	..	..	..	..	..
8	Bordeaux	..	×	×	..	×	×	×
	Lime sulfur	×	..	..	..	..	..	..
9	Bordeaux	..	×	×	×	..	×	×
	Lime sulfur	×	..	..	..	..	..	..
10	Bordeaux	..	×	×	×	×	..	×
	Lime sulfur	×	..	..	..	..	..	..
11	Bordeaux	..	×	×	×	×	×	..
	Lime sulfur	×	..	..	..	..	..	..
12	Bordeaux	..	×	×	×	×	×	×
	Lime sulfur	×	..	..	..	..	..	..
13	Bordeaux	..	×	×	×	×	×	×
14	Bordeaux	..	..	..	..	..	..	×
	Lime sulfur	×	×	×	×	×	..	..
15	Bordeaux	..	..	..	..	..	..	×
	Lime sulfur	×	..	..	..	×	..	..
16	Bordeaux	..	..	..	..	..	..	×
	Lime sulfur	×	×	×	×	..	..	..
17	Lime sulfur	×	×	×	×	..	×	..
18	Bordeaux	..	..	..	..	..	..	×
	Lime sulfur	×	..	×	×	×	..	..
19	Bordeaux	..	..	..	..	..	..	×
	Lime sulfur	×	..	×	×	..	..	..

NOTE.—All Bordeaux was of the 3-4-50 formula. All lime sulfur was of the 1-50 formula, commercial 32° Baumé. All sprays combined with powdered arsenate of lead 1-50.

ducted by growers under the supervision of the writer, and the results of the experiments of the writer are based on field work of three seasons at several localities in Illinois. The control work has been largely of a demonstrative nature and on a small scale, and while extensive data have not been obtained, the results are sufficiently conclusive to warrant the statement that successful control of the disease with sprays is possible in even the most seriously infested orchards.

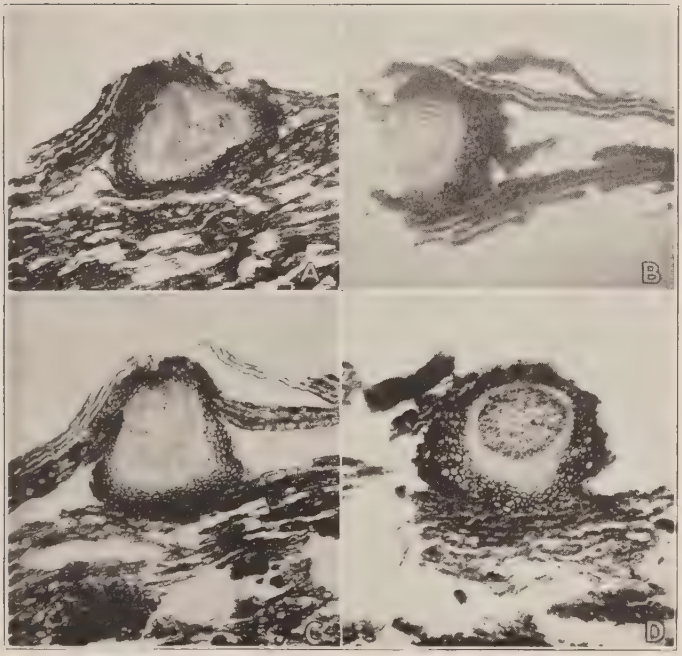

PLATE 4.—SECTIONS THRU PYCNOSCLEROTIA

(A, C) From cankers sprayed late in the dormant season with copper sulfate; (B, D) from cankers not sprayed in dormant season, Anna, May, 1920.

In 1920 at Anna

The spraying experiments for the control of apple blotch were conducted in a block of Duchess trees in the Anderson orchard. The trees were about fifteen years old, in good vigor, and they seemed not to be weakened from apple blotch altho cankers were sufficiently abundant to cause severe injury to the entire apple crop in the absence of sprays. In June, it was found that on unsprayed trees sixty apples picked at random showed on each apple an average of eighteen blotches.

The orchard was divided into plats of four trees each. Various schedules with applications of Bordeaux 3-4-50 and lime sulfur 1-50 with arsenate of lead were employed (Table 20). The schedules called for applications at two, three, four, five, six, seven, and eight weeks after the fall of the petals. Certain applications were omitted in some plats, since the purpose of the experiment was to determine which schedule and treatment would give most satisfactory control. A sufficient number of unsprayed trees was left for adequate comparison. The spraying was done with a power sprayer and bamboo rods were used for all of the summer sprays.

The dormant spray of lime sulfur was applied when the buds were opening and showing green (March 28 and 29), the cluster-bud spray of lime sulfur (1-40) was applied on April 17 and 18, and the calyx spray of lime sulfur and lead arsenate on April 26 and 27 when the petals were 75 percent fallen. The spray two weeks after petal fall (commonly called the first blotch spray), was delayed until seventeen to nineteen days after the fall of the petals (May 14 and 15). No difficulty was encountered in the application of the remaining sprays.

The fruit was harvested July 5 and since poor control was obtained in all of the plats, no attempt is here made to present the results of the treatments, altho the study of the results afforded a means of explaining the failures and gave evidence regarding the time and conditions associated with infection. The failure to apply the first blotch spray on time—two weeks after petal fall and prior to the rainy period of May 11 to 13—and the fact that rains were continuous during the period May 11 to 21, favored extensive infection of the fruit and foliage. Even from plats receiving all of the other sprays in the schedule the percentage of blotched fruit was almost equal to that from unsprayed trees altho the number of infections on the fruit was considerably less. The results emphasized the fact that the most extensive infections of the season may occur prior to the three-weeks application. The serious injury to the fruit from early applications of Bordeaux, i.e., at petal fall and two weeks after petal fall, and the absence of injury from treatments of lime surfur at these intervals, demonstrated that lime sulfur is the more desirable spray for early applications.

In 1921 at Anna

In 1921, spraying for apple blotch control was conducted in a block of Benoni trees thirty-five years of age in the Miller orchard. The trees were badly cankered and the fruit had been blotched severely in previous years in the absence of sprays. The age of the trees necessitated renovation, which consisted in the removal of many of the top branches, dead wood, and crowding branches; a more uniform distribution of the sprays thus being possible. Unfortunately late frosts killed most of the blossoms; however, a sufficient amount of fruit set to warrant the continuation of the experiment.

Bordeaux, hydrated lime-Bordeaux mixture, and homemade lime sulfur testing 31° Baumé were used as sprays, and all of the applications were combined with powdered arsenate of lead in the proportion of 1 pound to 50 gallons of water. The spraying was done with a power sprayer at a pressure of 250 pounds and rods were used exclusively.

The dormant spray was applied to all of the plats on March 20 when the fruit buds were beginning to show pink. It served the purpose of both the dormant and cluster bud sprays. The treatment was homemade lime sulfur testing 31° Baumé used in the proportion of 1 gallon of lime sulfur to 7 gallons of water. The calyx spray was applied on April 9, three days after the recorded date of petal fall (April 6) with the same fungicide in the proportion of 1-35 and with the addition of powdered arsenate of lead (1-50). The season was abnormal and the fall of the petals occurred unusually early.

The treatments were made at intervals of two, three, four, five, six, and seven weeks after petal fall. Various omissions, and alternations between lime sulfur and Bordeaux, were made in the spray schedule (Table 21). It was intended originally to omit the two-weeks spray in Plats 2, 6, 12, and 15, but because of the high wind prevailing two weeks after the fall of the petals it was impossible to spray the rest of the orchard without spraying the trees in these plats, especially on the leeward side of the trees. The remaining summer sprays were applied under ideal weather conditions. Six trees were maintained as checks, three of which, isolated from the orchard by a peach orchard, had been treated earlier in the season with homemade lime sulfur (31° Baumé, 1-3½). As previously stated, this spray had relatively no effect upon the spores, because of the weakness of the fungicide and its poor application under conditions of strong wind. Consequently, these three trees have been considered in the same class with the trees in Plat 15, which were not sprayed at all.

Because of the late frosts, the fruit was thinned out severely and the result of this, combined with heavy pruning, had the effect of

TABLE 21.—PLAN OF APPLE BLOTCH CONTROL EXPERIMENT, MILLER ORCHARD, ANNA, 1921

Plat No.	Treatment	Applications and dates					
		2 wks. Apr. 21	3 wks. Apr. 27-28	4 wks. May 3-4	5 wks. May 12	6 wks. May 18	7 wks. May 29
1	Hydrated lime bordeaux	..	×	×	..	×	..
	Lime sulfur	×	..	..	..	..	..
2	Hydrated lime bordeaux	..	×	×	..	×	×
3	Hydrated lime bordeaux	..	..	×	..	..	..
	Lime sulfur	×	..	..	..	..	..
4	Hydrated lime bordeaux	..	×	..	×	×	×
	Lime sulfur	×	..	..	..	..	..
5	Bordeaux	..	×	×	×	×	×
	Lime sulfur	×	..	..	..	..	..
6	Bordeaux	..	×	×	..	×	..
7	Bordeaux	..	×	×	..	..	..
	Lime sulfur	×	..	..	..	..	..
	No dormant spray	..	..	..	..	..	..
8	Bordeaux	..	×	..	×	×	×
	Lime sulfur	×	..	..	..	..	..
9	Bordeaux	..	..	×	..	×	..
	Lime sulfur	×	..	..	..	..	..
10	Lime sulfur	×	..	×	..	×	..
11	Bordeaux	..	..	..	..	..	×
	Lime sulfur	×	×	..	×	×	..
12	Bordeaux	..	..	..	..	..	×
	Lime sulfur	..	×	×	..	..	..
13	Lime sulfur	×	×	×	..	×	..
14	Lime sulfur	×	..	×	..	×	..
15	Check	..	..	..	..	..	..

NOTE.—All hydrated lime Bordeaux was of the 3-5-50 formula. All Bordeaux was of the 3-4-50 formula. All lime sulfur was of the 1-36 formula (homemade 31° Baumé). All sprays combined with powdered arsenate of lead 1-50.

producing large apples. Approximately eighty bushels of apples were harvested from the forty-seven trees in the orchard, altho some trees bore no fruit. The apples from the sprayed trees were free of disease and spray injury, and the control of apple blotch was perfect. The fruit from the check trees and the drops from these trees were gathered and sorted into three classes, namely, blotch free, slightly blotched, and seriously blotched (Table 22).

The records of natural infection for the season of 1921 at Anna show that a light primary infection occurred as early as April 26 and 27, or nineteen to twenty-one days after petal fall, but since all of the trees in the orchard received spray two weeks after petal fall (April 21) infection was prevented. The next—the first heavy infections—occurred in the period May 9 to 11. Prior to this many of the plats had already received three blotch sprays, namely two weeks (April 21), three weeks (April 27 and 28), and four weeks

(May 3 and 4) after petal fall, and since every plat received the two-weeks spray and either the three-or four-weeks spray as the plan of the experiment shows, (Table 21), no infections resulted.

TABLE 22.—RESULTS OF THE SPRAYING EXPERIMENT FOR THE CONTROL OF APPLE BLOTCH, ANNA, 1921

	Number apples examined	Number blotch-free	Number blotched			
			Slightly	Severely	Total	Percentage
Unsprayed....	1,379	186	446	747	1,193	86.5
Sprayed.....	....	Perfect control in all plats.....	0	0	0	0

In 1922 at Urbana

The Urbana orchard consisted of several winter varieties of apples, some trees of which were severely cankered with apple blotch and black rot. The trees were about thirty years old, high, and bore a considerable amount of dead wood. In order to improve the trees for spraying a heavy pruning was resorted to in the dormant season. The setting of fruit in 1922 was small and altho some trees bore heavily, the amount of fruit on others was insignificant, and too small for the purposes of the experiment.

The spraying was done with a power sprayer and both guns and rods were employed. The dormant spray of commercial lime sulfur (33° Baumé, 1-8) was applied late in the dormant season, on April 3

TABLE 23.—TREATMENTS AND TIME OF APPLICATION OF SPRAYS IN THE WEBBER ORCHARD, URBANA, 1922

Application	Treatment	Time of application
Cluster bud.....	Lime sulfur (1–40) lead arsenate (1–50).....	April 12
Calyx.....	Lime sulfur (1–50) lead arsenate (1–50).....	May 2 (Petals fallen 75%)
Two weeks.....	Lime sulfur (1–50) lead arsenate (1–50).....	May 15
Three weeks....	Lime sulfur (1–50) lead arsenate (1–50).....	May 23
Four weeks.....	Lime sulfur (1–50) lead arsenate (1–50).....	May 31
Six weeks.....	Lime sulfur (1–50) lead arsenate (1–50) lime (1–50)...	June 13
Ten weeks.....	Lime sulfur (1–50) lead arsenate (1–50) lime (1–50)...	July 11

(Table 23). Three trees were left unsprayed excepting for the dormant, cluster bud, and calyx applications.

On July 23, a record was taken of the amount of blotch on dropped apples from the check trees (Table 24). There were no dropped apples from the sprayed trees and careful observations of these trees in the latter part of July testified to the absence of blotch on the fruit and foliage. On the unsprayed trees the fruit and foliage chiefly on the lower branches were infected. The orchard was given no attention after July and since a serious outbreak of codling moth, combined

with black rot infection, occurred in August, much of the fruit was wormy and infected with black rot at harvest time. Undoubtedly the application of an insecticide in August would have protected the fruit against the third-brood codling moth, and its combination with a fungicide would have safeguarded the season's growth against late infections of apple blotch, had the weather conditions been favorable. In September and October, and again in March, 1923, the season's twig growth was examined for bark cankers. These were found largely on the water sprouts, and only on the unsprayed trees. The two-, three-, four-, six-, and ten-weeks spray schedule, therefore, demonstrated its efficiency in controlling apple blotch in this orchard in 1922. The exclusive use of lime sulfur in all of the sprays and the

TABLE 24.—NUMBER OF DROPPED BLOTCHED AND BLOTCH-FREE APPLES FROM CHECK TREES IN THE WEBBER ORCHARD, URBANA, 1922

	Total number apples examined	Number blotch-free	Number blotched			
			Slightly	Severely	Total	Percentage
2 trees, undetermined variety	860	741	97	22	119	13.8
1 tree, Ben Davis	326	121	77	128	205	63

absence of spray injury on the fruit testified to the decided effectiveness of lime sulfur for the control of apple blotch.

In 1922 at Lilly

The main purpose of the work at Lilly was to demonstrate control of apple blotch with the proper spray schedule. The trees were of the Northwestern Greening variety on which the disease was making serious progress. Attempts by the owner to control the disease had failed every season since its first appearance in 1917. In 1921 the fruit from many of these trees was ruined by blotch. Approximately twenty-five trees were used in the plan of the experiment and two of these were not sprayed.

The calyx spray was applied on May 5 and 6, when 75 percent of the petals had fallen. The spraying was done with a power sprayer and both spray gun and rods were employed (Table 25). The orchard was visited on July 20 and no blotch could be found on the fruit and foliage of the sprayed trees, but it was common on the unsprayed trees. During the period May 23 to 26, seventeen to twenty-one days after petal fall, heavy infections occurred at Lilly, symptoms of which were apparent on the fruit and foliage by June 7 and 8. The absence of the disease on the sprayed trees indicated that the two-weeks spray (May 19) was applied at the right time. The perfect results demonstrated the success of the two-, three-, four-, six-, and ten-weeks spray schedule.

At Rome a control demonstration was undertaken on six Northwestern Greening trees as a check on the results at Lilly. Local help was relied upon to apply the two- and three-weeks sprays of lime sulfur, but no accurate information could be obtained as to the time and manner of these applications. The writer applied the four-weeks (June 9) and six-weeks (June 23) sprays of Bordeaux. No attention was given to the orchard after June 23 (six-weeks spray) and consequently no data were obtained on the condition of the crop at harvest time. There was a considerable amount of disease on the fruit and foliage as early as June and the infections were traced to the condi-

TABLE 25.—TREATMENT AND TIME OF APPLICATION OF SPRAYS AT LILLY ORCHARDS, 1922

Application	Treatment	Time of application
Two weeks	Lime sulfur (1–40) lead arsenate (1–50)	May 19
Three weeks	Lime sulfur (1–40) lead arsenate (1–50)	May 26
Four weeks	Lime sulfur (1–40) lead arsenate (1–50)	June 2
Six weeks	Bordeaux (3–4–50) lead arsenate (1–50)	June 16
Ten weeks	Bordeaux (3–4–50) lead arsenate (1–50)	July 20

tions of May 23 to 27, or two and one-half to three weeks after petal fall. It was evident that the early infections were not suppressed, altho spraying had the effect of reducing the amount of infection more than in previous years.

SUMMER SPRAYING: CONCLUSIONS

While the spraying experiments have not been extensive and on a large scale, the results, together with the knowledge of the life history of the fungus, make it possible to arrive at recommendations for the successful control of the disease with sprays.

The infections are most frequent in the spring and consequently the application of sprays must be frequent at this time of the season in order to keep the growth protected, and as the summers are usually dry, applications are necessary only at wide intervals. Since the primary infections usually occur from two to three weeks after the petals have fallen, the first spray for apple blotch must be applied between ten days and two weeks after petal fall and not later than two weeks after petal fall. This recommendation applies to all varieties of apples. It is the critical application of the season and the production of blotch-free apples depends upon the timely and thoro application of the first spray. The suppression of the first infections is significant in that it prevents the multiplication of the disease in the orchard.

In addition to the two-weeks spray, later sprays must be applied in the order of three, four, six, ten, and fifteen weeks after the petals have fallen, the last two applications conforming to the period of the

second- and third-brood codling moth. They are particularly necessary for susceptible fall and winter varieties of apples. In view of the duration of the infection period the need of so many sprays is obvious. Since the spraying with arsenate of lead for the second- and third-brood codling moth is generally practiced, the addition of a fungicide at these intervals is only a matter of some small expense compared with the value of the returns. The two-, four-, six-, ten-weeks schedule of Beach[5] of hydrated lime-Bordeaux (3-5-50), the preliminary schedule of Rolfs[72] of Bordeaux at two and four to five weeks and arsenate of lead at seven to eight weeks after the fall of the petals cannot be recommended in Illinois since the period between the two- and four-weeks applications is entirely too long and since no provision is made for late infections, and further because under Illinois conditions Bordeaux cannot safely be used ordinarily at two weeks after the fall of the petals. Likewise, the two-, three-, four-, five-, seven-, ten-weeks schedule of Brock[16] of early applications of lime sulfur and summer applications of Bordeaux, makes no provision for late seasonal infections. It is more profitable, and as effective, to omit the five- and seven-weeks applications and to make an application at six weeks after petal fall, especially for early varieties like the Duchess, Benoni, and Yellow Transparent, which usually require from nine to ten weeks to mature. Ordinarily, the conditions are dry in Illinois after four weeks after petal fall and with the protection afforded by the two-, three-, and four-weeks applications it is unnecessary to make the next application until six weeks after petal fall. The six-weeks application for early varieties also is as effective as the seven-weeks application for the protection of the growth until harvest.

The time of the applications is of more importance than the nature of the spray. Lime sulfur and Bordeaux are still considered the standard and dependable sprays for Illinois orchards. They have been employed repeatedly by the writer in the control of apple blotch with equal and highly favorable results, thus verifying earlier literature. However, because of the greater adhesive quality and toxicity of Bordeaux this fungicide is the better spray for long periods; nevertheless, with the schedules employed, lime sulfur alone has given perfectly satisfactory results. Both of these fungicides should be employed in the proportions recommended under Illinois conditions; namely, lime sulfur 32° Baumé, 1-40 and Bordeaux 3-4-50. The selection of either one of these fungicides for any particular application depends upon the variety and the prevailing weather conditions. The moist cool weather of the spring months in Illinois prohibits the use of Bordeaux and the hot dry weather of the summer prohibits the use of lime sulfur. The general fungicidal effect without burning can successfully be obtained by employing lime sulfur for the first one or two blotch sprays—at two weeks and three weeks after petal fall—

and Bordeaux for the remaining applications. The results of the writer, and those of growers, with hydrated lime-Bordeaux have demonstrated that its efficiency for apple blotch control is equal to that of the ordinary Bordeaux prepared from slaked lime and that its use also must be restricted to applications later than two and three weeks after petal fall.

The success in controlling apple blotch lies in keeping the surface of the fruit, foliage, and growing twigs covered with spray during the growing season. The failures have been, and are, due to delay in the first application, and to making the applications too far apart. A power sprayer furnishing pressure of 225 to 300 pounds is necessary to apply the spray forcibly (as a fine mist), in order to reach every portion of the tree.

OTHER ASPECTS OF CONTROL

Soil Treatments

The results in Illinois from fertilization of blotch infected orchards with sodium nitrate or ammonium sulfate gave no evidence of increased resistance of the bark to apple blotch nor any reduction in the amount of the disease. Rather the opposite was true, since the increased succulence of the growth as the result of soil treatments was favorable for infection and for the growth of the fungus.

Fertilization, however, is necessary for the rejuvenation of badly infected trees and the spraying program for the control of blotch in badly infected orchards should include some attention to the needs of the soil, cultivation and the use of nitrogenous fertilizers being desirable. Since the trees respond actively to soil treatments they must be sprayed regularly in accordance with the recommended spray schedule in order to maintain growth free of infection. Following such a procedure, some varieties of trees may eventually be freed of bark cankers.

Pruning

The removal of infected branches and twigs, primarily to decrease the amount of apple blotch infection, is impracticable and seems never to have been adopted by growers. The practice causes excessive pruning and involves much time and expense.

Pruning for the purpose of removing dead wood and crossed branches, thus opening the trees to uniform distribution of the spray, is a worthy practice. The succulent growth which may be induced as the result of this pruning can be maintained free of infection by spraying.

Surgery

Even tho histology of the bark cankers shows that removal of the fungus from nursery stock or young trees in the orchard by cutting is a simple operation, the method cannot be recommended since the cankers are frequently too numerous, and often too small to be detected by the growers. The method is tedious and impracticable, requiring reinspection of the trees and repetition of the process, for which reasons growers cannot be induced to undertake the practice.

It is more desirable to reject diseased trees from the nursery and thus keep the fungus from the orchard.

Protective and Preventive Measures

The means of avoiding apple blotch in the young orchard rest largely with the nurserymen. Nurserymen grow and sometimes sell diseased trees, and it is known that they have received blotch-infected apple seedlings from localities where apple blotch is seriously prevalent. It is desirable, therefore, that measures be enforced in the separate states that will insure rigid inspection of all apple seedlings and the exclusion from shipment of all stock that is infected.

In order to insure disease-free apple seedlings the seedling growers should be required to spray the nursery rows during the growing season. This is a protective measure for the thousands of growers and nurserymen in the United States who are necessarily dependent for their stocks upon the American growers of seedlings.

In the second place, local nurserymen must protect themselves against the receipt of infected seedling stock from the seedling growers, and the steps which they may wisely take will consist of rigid inspection of the seedlings and the rejection of all infested stock intended for budding. If the seedling stock is used for grafting there is no danger of distributing the disease provided healthy scions are employed. Unless it is possible to obtain blotch-free American grown apple seedlings, it may be wise for nurserymen to use foreign-grown seedling stock.

Local nurserymen must be cautious in the selection of buds and scions, and as a measure of safety should select them from trees which they know are free of blotch cankers. As long as spraying is directed primarily for the protection of fruit, infections of the bark will occur; thus the danger of selecting diseased buds and scions is evident, especially among early varieties, such as Yellow Transparent, Benoni, and Duchess. Since the fungus persists for many years in the bark of some varieties, the policy of destroying cankered trees in the nursery rows should be followed rigidly in order to safeguard other trees from infection.

The growers can save themselves much expense and unnecessary losses later in the fruiting period of the trees by carefully examining the young trees upon receipt from the nurseries and rejecting those which show evidence of cankers. The planting of healthy trees is strongly recommended and is most economical in the end. If the grower is not sure of obtaining blotch-free trees from nurserymen in the blotch area it may be wise for him to buy from nurseries in states where the disease is known not to exist.

Selection and Location of Varieties

It is imperative to select varieties which are bark-resistant, and to plant them at a distance from bark-susceptible varieties.

Growers are divided in their opinions as to the selection of varieties, even among those seriously susceptible to fungi. In the central and western sections of the state, commercial growers still favor the Ben Davis in spite of the fact that all our serious apple maladies are common on this variety, blotch, blister canker, and scab being especially so. In southern Illinois, owing to this susceptibility, the Ben Davis has become unpopular and is no longer planted. Likewise, there is difference of opinion in regard to the Duchess variety, which in Illinois ranks among those most susceptible to apple blotch; yet some growers realize that control is possible and they feel that the high market value of this apple warrants planting it. It must be emphasized, however, that the more susceptible the variety the more expensive its culture, and unless growers feel that they can care for the trees in the proper manner they should select varieties which are relatively bark-resistant, and by all means reject varieties very susceptible to bark infection (Table 14).

The writer opposes the selection of bark-susceptible varieties, since it is obvious that the control of insects and fungi is a serious problem to be avoided when possible. However, if a grower insists upon planting these varieties he should separate them well from resistant ones so that he may concentrate his spraying, especially during the busy seasons, within a relatively small area and thus save time and labor.

RECOMMENDATIONS FOR CONTROL

The recommendations for the control of apple blotch may be considered under two headings—*pruning* and *spraying.*

In *pruning,* aim to remove crowded and dead branches in accordance with general pruning methods so that the sprays may reach every apple. Remove surplus water sprouts; they are particularly undesirable since they are very susceptible to infection. In renovat-

ing the orchard, leave only those water sprouts which are expected to be of some use in developing the framework of the trees.

All pruning should be done prior to the dormant spray.

Trees must be sprayed uniformly. The practice of applying the spray from one side of the tree with the wind, or from one side of the tree for one application and from the opposite side for the succeeding application, cannot be recommended. Either guns or rods may be employed with disc nozzles having small openings. High pressures of 225 to 300 pounds are desirable to force the spray into the trees as a fine mist. It is necessary to apply the sprays on time with reference to the time the petals have fallen (75 percent fallen) and in accordance with the following schedule.

Dormant Spray.—This application should be made late in the dormant season, preferably when the tips of the buds are showing green (delayed dormant), using commercial lime sulfur 32 or 33° Baumé in the proportion of 1 gallon of lime sulfur to 8 gallons of water, or copper sulfate in the proportion of 1 pound to 10 gallons of water. Spray thoroly and if severely cankered, drench the trees.

First Blotch Spray.—Apply a few days earlier than two weeks after petal fall and complete the application by two weeks after petal fall. Use lime sulfur in the proportion of 1 gallon of lime sulfur to 50 gallons of water; and for every 50 gallons of spray solution, add 1 pound of powdered arsenate of lead.

Second Blotch Spray.—At three weeks after the fall of the petals, use the same treatment as for the first blotch spray.

Third Blotch Spray.—At four weeks after the fall of the petals, use Bordeaux in the proportion of 3 pounds of copper sulfate, and 4 pounds of slaked lime[a] to 50 gallons of water.

Fourth Blotch Spray.—At six weeks after the fall of the petals, use the same treatment as for the third blotch spray.

Fifth Blotch Spray.—At nine or ten weeks after the fall of the petals, use the same treatment as for the third blotch spray, adding 1 pound of powdered arsenate of lead for every 50 gallons of spray. The time of this application corresponds to that of the second-brood codling moth.

Sixth Blotch Spray.—Apply in the middle of August. The time of this application corresponds to that of the third-brood codling moth. Use the same materials as for the fifth blotch spray. This is the last spray for apple blotch and is intended to protect the fruit of late varieties against late infections. Its application in some seasons for blotch may not be necessary, depending upon the weather.

[a] If hydrated lime is used instead of rock lime use 5 pounds to 50 gallons.

For early varieties, such as Yellow Transparent, Duchess, and sometimes Benoni, only the two-, three-, four-, and six-weeks applications are necessary to protect the fruit until harvest. Usually for the Benoni and other varieties that are harvested around ten weeks after blooming an application eight weeks after the fall of petals is desirable in seriously cankered orchards. For late summer varieties the ten-weeks spray is desirable for blotch, as well as for the second-brood codling moth. It is impossible to make any definite recommendations of late sprays for every orchard and every section of Illinois. The need of these late sprays should be determined by the grower, and his decision should be guided by the weather peculiar to his section and by the amount of infection in the orchard.

In addition to pruning and spraying, *soil treatments* in the form of cultivation and fertilization are particularly necessary in old and weakened orchards.

In planting the orchard, varieties should be selected which are relatively resistant to bark infections. If bark-susceptible varieties of high commercial value are desirable they should be planted at a distance from bark-resistant varieties.

All infected trees from the nursery should be rejected.

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